SAVING MONEY AND THE ENVIRONMENT THROUGH ENERGY EFFICIENCY

Options for Developing, Financing and Implementing Good Energy Management Programs

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Executive Summary

Energy use can account for up to one third of the operating budget of a wastewater treatment facility. Energy use is also closely linked to environmental impacts and contribute to environmental problems that are felt locally, regionally, and globally. For example, for every 100 kilowatt-hours of energy generated from carbon-based fuels, nearly 130 pounds of pollutants are discharged.

Many of the older treatment plants in New England were designed at a time when energy conservation was not an issue - energy was inexpensive and considered relatively inexhaustible. Treatment facilities built in the 1970's and 80s are likely at or near their design life and will soon be in need of repair, upgrade or replacement. An ideal time to evaluate and improve your energy management practices is when repairing or upgrading your facility.

This document is part of a cooperative initiative among EPA-New England, the New England states, and the New England Interstate Water Pollution Control Commission to help educate municipal facilities about energy management and options. It provides information about the opportunities for municipal wastewater treatment facilities to better understand their energy use. It also discusses ways to improve efficiency, which can lead to reduced costs and fewer environmental impacts. This initiative also includes energy management workshops to be held in each of the six New England states and preliminary energy assessments of five New England treatment facilities that are included in **Appendix E**.

Introduction

Human activities rely on the combustion of carbon based fuels for energy, which in turn has an important impact on our environment. Such combustion unavoidably results in byproducts that are released, primarily into the atmosphere, where they accumulate. There are over five hundred wastewater treatment facilities in New England with the potential to prevent hundreds of tons of air pollutants and save tens of thousands of dollars each year. By evaluating your wastewater system, you may be able to reduce your energy costs and help the environment.

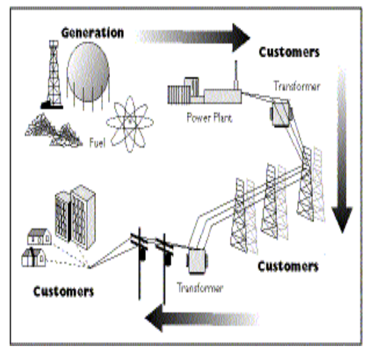
This document outlines the major areas where a facility may find opportunities to better manage the use of energy. Evaluating a treatment system to increase efficiency and reduce costs can be segmented into the following areas:

* Energy Costs and Utility Rate Structure
* Pump System Efficiency
* Mechanical Efficiency
* Electrical Efficiency

Many commercial and industrial facilities have benefitted financially by making energy improvements. Municipalities can also benefit from improved energy management and help the environment.

Utility Industry

Your Choice of Electricity



Restructuring of the electric utility industry, sometimes called deregulation, is the separation or unbundling of charges for energy generation and transmission/distribution. Restructuring also transfers the control of ***energy generation*** from the government regulators to the free market. Simply put, under restructuring, the customer can choose which company will produce their electricity. The delivery of electricity will continue to be provided by the distribution company, formerly the companies that provided all the electric service.

You can now choose a new supplier or you can do nothing, receive the Standard Offer and choose when you are ready. The choices you have include:

* Choose an Electricity Supplier
* Join a Buying Group
* Receive Standard Offer Service

Customers may shop around for electricity supply based on:

* price
* terms of contract
* customer service options
* mix of renewable and non-renewable
* energy sources

Electric restructuring is an important issue for New England, since we have some of the highest electric rates in the country. While there are no guarantees, a fully competitive market should, over time, help to lower the overall electric rates so they are closer to the national average.

With restructuring, consumers can have a direct positive effect on the environment. That's because consumers have the option to choose suppliers with power plans that include more renewable energy in their power mix. Renewable energy typically costs more to produce, but with more consumer support, the costs of renewable power should go down. You can affect the availability and affordability of renewable energy by choosing an energy supplier who is more environmentally responsible.

Group Buying

Buying groups, sometimes known as aggregates, enter purchasing agreements with electricity suppliers at favorable rates or terms for their members. Group buying can give a facility the buying clout of a larger consumer and may receive advantages as discounted prices, special billing services, or power from preferred sources- such as renewable power. The supplier benefits by having a ready made group of consumers ,which reduces marketing costs, and having a predicable customer load which lessens their risk.

Joining a buying group means entering into a business relationship with the rest of the group. As with any business arrangement, a facility must look carefully at the group's make-up, financial viability and goals. For further information on utility restructuring or group buying contact your state Public Utilities Commission (Appendix A).

Evaluate Your Costs

Understanding your utility bills, present and future, and how charges are assessed is also essential to your strategy to reduce your energy costs. In fact, most bills include two, three or four separate charges. While your utility bill indicates how much energy and power you used, the rate structure is the guide for determining how costs are allocated. Ask your electric utility and energy suppliers for a printed rate schedules that describe the various rates available and illustrate how charges are calculated. Most utilities are willing to change a customers rate schedule free of charge, providing you qualify for the new rate. **Appendix B** explains further about understanding your utility bill.

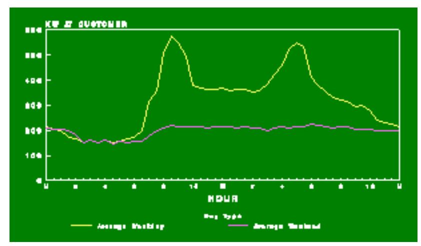
Conduct an Energy Assessment

To better understand where your energy is being used and what improvements can be made, conduct an energy assessment of your facility . An energy assessment can: identify where energy is wasted; help develop an energy purchasing strategy; provide a baseline for tracking energy use; and provide a basis for an action plan (see **Appendix C).**

Determining your current electricity costs in a meaningful measure, such as dollars per million gallons treated, can be useful. This allows you to establish a baseline operating cost against which to measure improvements as well as compare to other facility operating costs. It is also a useful tool when explaining energy or cost issues.

In general, restructuring should result in lower rates for consumers. Like all consumers, municipal facilities will be in a much better position if they understand how they use energy and are informed about the changes occurring in their state.   Your current utility and state utilities commission are able to advise you on how restructuring may affect you (see **Appendix A**). If you choose to do nothing, your utility, or a utility appointed by the utilities commission, will continue to provide you with reliable power. However, we encourage you to take the time to investigate the options available to you through the restructuring of the industry.

Utility Assistance Programs



Electric utility Demand Side Management (DSM) refers to programs implemented by utilities to help customers focus on energy conservation and energy management techniques. The customer benefits by managing their energy needs better and lowering their costs; the utility benefits because it helps defer the need for new sources of power; and the environment benefits by reduced air emissions. These benefits are primarily accomplished through efficiency programs that reduce overall energy use, and peak load (energy use) reduction programs, that focus on reducing energy use during periods of high consumption. If you have not already done so, assess the benefits of boosting efficiency and adjusting energy use to off peak hours to take advantage of lower utility rates.   You may be surprised at how much energy can be saved. **Appendix C** provides some simple strategies for managing your energy demand.

Many utilities will offer a free assessment of your facility's energy practices. Where equipment replacement is recommended, rebates or discounts may be available. Contact your utility account representative for more information on product and services. However, assessments performed by the utilities are usually confined to evaluating the use of energy over an operating day and the efficiency of energy consuming equipment, such as motors.   The utility does not commonly evaluate a facility's treatment options or pumping systems.   Before making improvements to electrical or mechanical equipment, it would be prudent to perform a pumping and aeration system assessment. There are engineering firms and energy service companies that can assess treatment systems as well as energy use and efficiency.

Some facilities may be tempted to wait and see what happens regarding utility restructuring, believing it may affect the economics of planning energy efficiency improvements. Generally, this is not wise. Most energy efficiency improvements have a fast payback time, and any delay in implementing them only causes your facility to continue to spend more than it needs to for energy.

Pumps and Pumping Systems

Each component of a pumping system (pumps, motors, pipes, drives, valves) has an efficiency, which together make-up the overall system efficiency. Because pumping fluids at wastewater treatment plants accounts for most of a facility's energy costs, using pumps efficiently can help minimize those costs. Department of Energy studies indicate that as much as 20% of the energy consumed in pumping can be saved by using pumps more efficiently.

Modern pumps can achieve as high as 90% efficiency when operating in the optimum range. Pumps are designed for the highest efficiency at a specific flow rate and head (elevation) condition. When operated at flow rates that are quite different the efficiency will be reduced. In fact, many pumping systems are not operated at the best efficiency. Although pumps do lose efficiency as they age, the flow requirements of a pumping system may have changed over time and it no longer operates in the best efficiency range.

For example, pump stations that are sized to handle high flows from a combined sewer system, or from groundwater infiltration, may operate inefficiently at normal wastewater flows. If a community has begun separating stormwater or infiltration from its sewer system, thereby reducing the flow, the pump system may no longer operate within their optimum efficiency range. Energy and money are being wasted.

A pumping system has three key elements: flow, static head, and frictional head. Each of these elements must be challenged to find the opportunities for improvements within a pumping system. **Appendix D** provides further tips on improvements to each of these areas. Below is a list of possible opportunities for savings.

* Reduce flow and total head requirements.
* Select the most efficient pump type and size (don't overemphasize the initial cost).
* If throttling flow evaluate the use of VFDs.
* Use two or more smaller pumps instead of one large pump.
* Maintain pumps and all system components to avoid efficiency loss.

In most applications, it costs much more to operate a pump for one year than it does to buy the pump. Considering the high energy costs in New England, a 20% reduction in operating costs can pay for the cost of a pump in about a year. Consider the following example.

A pump station operates 75% of the time at only 60% efficiency. A pumping assessment indicates a new 25 horsepower motor and pump would increase the efficiency to 80%.

New Pump and Motor Cost = $ 4,500
Annual Operating Cost at 60% = $ 20,422 (at $0.10/kWh)

Annual Operating Cost at 80% = $ 15,316
Savings = $ 5,106
Simple Payback = $ 4500 /$ 5,106 = 10.5 months

This example uses round numbers, and each situation needs to be evaluated, but the potential savings in energy and cost are considerable. Through a pumping system evaluation you may find opportunities to improve your system and begin saving on energy costs.

Motors: Are energy efficient motors really worth it?

Although the initial cost of an energy efficient motor can be fifteen to thirty percent higher than for a comparable standard motor, the savings usually offset the higher capital cost in two years or less. Because pumps and blower motors account for eighty to ninety percent of the energy costs at wastewater treatment facilities, energy efficient motors can play a major role in reducing a facility's operating costs. The lifetime energy costs to operate a continuous-duty motor are ten to twenty times higher than the original motor price. Use the following formulas to calculate the annual energy savings and simple payback from selecting a more efficient motor. Simple payback is defined as the time required for the savings from an investment to equal the initial cost.

Annual Energy Savings, kWh/yr= hp x L x 0.746 kW/hp x hrs x (100/Estd- 100/Eee)
Annual Cost Savings, $/yr = Kwh/yr saved x utility rate

hp = rated motor horsepower
L = load factor as decimal
Estd = % efficiency standard motor
Eee = % efficiency energy efficient motor
hrs =Annual operating hours

$$\text{Simple Payback (Years)} = \frac{\text{initial cost}}{\text{Annual cost savings}}$$

Below is a comparison between some common standard efficiency motors and energy efficient motors. As you can see, it does not take long to pay back the higher initial cost of an energy efficient motor, and begin saving money and energy.

COMPARISONS BETWEEN STANDARD-EFFICIENCY (SE) MOTORS AND ENERGY-EFFICIENT (EE) MOTORS

Motor (hp)	Purchase Cost ($)			Efficiency (%)		Annual Savings		Simple Payback (years)
	SE	EE	Difference	SE	EE	kWh	$	
10[a]	614	795	181	86.5	91.6	2103	210	0.86
25[a]	1230	1608	378	88.1	94.2	6004	600	0.63
50[a]	2487	3207	720	90.6	95.0	8352	835	0.86
100[a]	5756	7140	1384	90.7	95.7	18,822	1882	0.74
200[b]	11,572	13,369	1797	94.6	96.1	10,782	1078	1.67
300[b]	15,126	18,385	3259	94.6	96.0	15,111	1511	2.16

Note: Based on 16 hr/day operation at 75% load and $0.10/kWh
[a] Reliance Standard-Efficiency and Premium-Efficiency Motors
[b] G.E. EnergySaver and Standard-Efficiency Motors

The above table ignores other potential benefits of energy efficient motors. A lower priced premium motor, a rebate program or increased reliability can make energy efficient motors even more cost effective. An evaluation of motor efficiency is usually combined with a **pumping system evaluation.**

Should I Rewind Existing Motor or Purchase New

Rewinding, or rebuilding, an electric motor involves replacing the internal components. Although failed motors can usually be rewound, it is often worthwhile to replace damaged motors with new energy efficient models to save energy, money and improve reliability. Here are a few rules of thumb to consider when deciding whether to rewind a motor or purchase a new one:

- Replace an existing premium motor if the repair cost is more than 60% of the cost of a new one.
- Intermittent or low usage- Use the lowest cost option that meets your operating requirements.
- Single shift operation, 2000 hrs/yr- Replace all low efficiency motors below 30 hp with premium efficiency motors. Consider repairing motors above 30 hp.
- Two shifts, 4000 hrs/yr- Replace all low efficiency motors below 100 hp with premium efficiency motors. Consider repairing motors above 100 hp.

- For continuous operation, 8760 hrs- Replace all low efficiency motors with premium efficiency motors.

When calculating the operating costs for rewound motors, deduct one efficiency percentage point for motors larger than forty horsepower and two points for smaller motors. As an example, a one point gain of motor efficiency for a twenty-five horsepower motor saves about $136/ year, or $ 2040 over its lifetime (based on $0.10/kWh, 75% load, and 15 year life). U.S. Department of Energy's MotorMaster software can help you compare efficiencies of like models and select the most appropriate motor for your application.

Variable Frequency Drives

A variable frequency drive (VFD) is an electronic controller that adjusts the speed of an electric motor. Most industrial AC (alternating current) induction motors manufactured in the US are designed to operate with a current that alternates in the direction of flow 60 times per second (HZ). If this frequency of alternation is changed, the speed of the motor changes. By controlling the AC frequency and voltage with a variable frequency drive, you control motor speed. Therefore, VFDs can provide continuous control, matching motor speed to the specific demands of the work being performed. Standard motor starters start motors abruptly, subjecting the motor to high torque and current surges up to 10 times the full-load current. In contrast, VFDs offer a "soft start" capability, gradually ramping up a motor to operating speed. This lessens mechanical and electrical stress on the motor system, reduces maintenance and repair costs, and extends motor life.

VFDs are increasing in popularity at wastewater facilities where the greatest energy use is from pumping and aeration- two applications particularly suited to VFDs. For applications where flow requirements vary, mechanical devices such as flow-restricting valves or moveable air vanes are often used to control flow. This is akin to driving a car at full throttle while using the brake to control speed. This process uses excessive energy and may create punishing conditions for the mechanical equipment involved. VFDs enable pumps to accommodate fluctuating demand, running pumps at lower speeds and drawing less energy while still meeting pumping needs. Figure 1 illustrates the reduced energy consumption of VFDs over valve control systems. With VFDs, wastewater treatment plants can more consistently maintain desired dissolved oxygen (DO) concentrations over a wide range of flow and biological loading conditions by using automated controls to link DO sensors to VFDs on the aeration blowers.

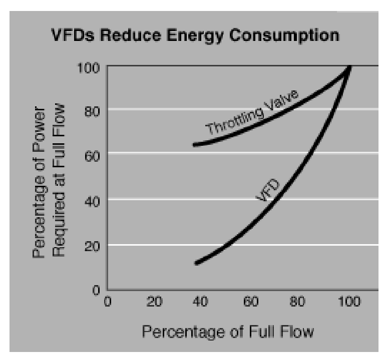


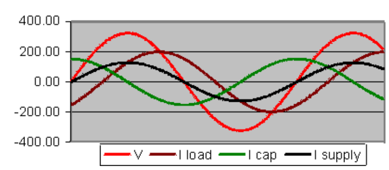
Figure 1. Energy consumption of VFDs and throttling valves.

Energy savings from VFDs can be significant. Even a small reduction in motor speed will significantly increase your energy savings. For example, a 20% reduction in motor speed can reduce the energy requirements by nearly 50%. Therefore, a pump motor that does not usually need to run at full speed can substantially reduce its energy use by using a VFD. For example, a 25-hp motor running 23 hours per day (2 hours at 100% speed; 8 hours at 75%; 8 hours at 67%; and 5 hours at 50%) can reduce energy use by 45% using a VFD. At $0.10 kWh, this saves $5,374 annually. VFDs work with most three-phase electric motors, so existing pumps and blowers that use throttling devices can be retrofit with these controls. VFDs can also be specified for new equipment.

Initial costs for VFDs can seem expensive, but payback periods for these drives can range from just a few months to less than three years for 25 to 250 hp models. In addition, savings from reduced maintenance and longer equipment life contribute significantly to achieving a rapid payback and long-term savings. Also, many electric utilities offer financial incentives that can reduce the installed costs of VFDs.

VFDs are not suited to all applications, such as flow that is relatively constant. Therefore it is important to calculate the benefits for each application based on the system variables such as pump size, variability of flow, and total head. As mentioned, it is prudent to first perform a pumping system assessment to determine if flow and energy requirements in the pumping system can be reduced before making other energy improvements.

Power Factor Correction



As with any equipment, an electrical system handles its job to some degree of efficiency ranging from poor to excellent. This measure of electrical efficiency is known as the Power Factor. Under ideal conditions the power factor would be 100%. However, motors and other inductive equipment (transformers, light ballasts) require energy that does no work and as a consequence, the power factor decreases.

Low power factor causes heavier currents to flow in distribution lines in order to provide needed kilowatts to the end user. Because the utility company must invest in oversized equipment to provide increased power to serve low power factor loads, a charge is commonly assessed on a facility's electric bill to recover the equipment costs and lost energy caused by low power factor. The direct cost of a low power factor usually shows up on the monthly bill as an extra charge. The assessed charges are not always readily obvious by looking at your bill. Some of the more common names for the charges are: power factor penalty, pf adjustments, or kVA demand, to name a few. Analyzing your utility bills will usually reveal if you have a power factor problem. Even if the utility does not bill directly for power factor, a low power factor can raise your kWh and demand billing. All utility companies can supply you with a rate schedule that explains their charges including power factor.

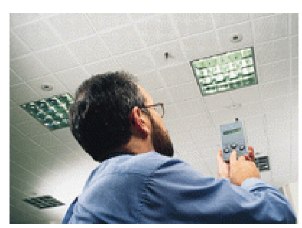
Many facilities can improve their power factor by ensuring their motors are not oversized and by installing power factor correction capacitors **(see Appendix C)**. However, the cost effectiveness of improving power factor depends on such variables as utility power factor penalties, the facility's need for additional electrical system capacity, and energy costs. The following example will give you an idea of the penalty for having a low power factor.

> A facility has an average monthly demand of 1200 kW and a power factor of 0.78. The utility charges according to kW demand (say $4.50/kW) and has a surcharge for power factors less than 0.95. The following formula shows a billing adjustment based upon a power factor less than 0.95.
>
> kW (billed) = kW demand x demand rate x 0.95/PF
>
> Monthly Utility bill with present power factor of 0.78:
>
> kW (billed) = 1200 kW x $4.50 x 0.95/0.78 = $6579
>
> Monthly Utility bill after power factor corrected to 0.95:
>
> kW (billed) = 1200 kW x $4.50 x 0.95/0.95 = $5400
>
> Annual Savings=($6579 - $5400) x 12 months=$14,148

In this example, if the organization supports cost saving projects with a payback of 3 years or less, then power factor correction equipment costing less than $42,000 would make this project acceptable, and profitable.

As you can see, to assess the benefits of installing equipment to correct your power factor it is critical to understand your electric bill and the utility's rate structure. Your utility can provide you with printed rate schedules that describe the various rates available and illustrate how charges are calculated. **Appendix B** explains further about understanding your utility bill. **Appendix C** provides some examples of managing energy use and improving power factor.

Lighting



Lighting is often overlooked for energy saving opportunities at treatment facilities because it is overshadowed by the energy use of motor and pumps. At other types of facilities (schools, police stations, office building) lighting is a major energy consumer and is one of the first areas evaluated to improve efficiency and reduce costs. For example, the increased cooling demand generated by inefficient lighting systems can add 10% to cooling energy costs. Many businesses are lowering their lighting and cooling bills by installing energy-efficient equipment. Likewise, municipal treatment facilities should also take full advantage of advances in lighting technology to reduce both the energy costs and the higher maintenance of older lighting systems.

Lighting technology and design have had many new developments in recent years. Technology improvements have increased lamp efficiency, improved color rendering and extended lamp life. New electronic ballasts enable fluorescent lamps to operate flicker-free, last longer, start faster and operate cooler. In addition, some ballasts provide smooth and silent dimming. Improvements in lighting fixtures offer better reflection of light and can reduce the number of bulbs needed. There have also been many developments in electronic controls for lighting, either daylight-linked or occupancy-linked. The payback for the costs of a lighting upgrade is typically between 1 and 3 years. Here is a simple example.

Existing Lighting system:

4- 40 watt T 12 fluorescent lamps (1.5 inch diameter by 4 feet)
2- 16 watt magnetic ballast
Time used: 3000 hours per year
Annual Cost: (192 watts x 3000 hrs) x 1 kW/1000watts x $0.10/ kW
Annual Cost = $ 57.60

Replacement Lighting system:

2- 32 watt T 8 fluorescent lamps (1 inch diameter by 4 feet)
1- 2 watt electronic ballast
1 - new Reflector Fixture
Annual Electric Cost = $ 19.80
Capital Cost for New Equipment = $65.00

$$\text{Payback: } \frac{\text{Capital Cost}}{\text{Annual savings}} = \frac{\$\ 65.00}{\$\ 57.60 - \$\ 19.80} = 1.7 \text{ years}$$

The above example shows the benefits of changing a lighting fixture which is working. For fixtures which are in disrepair (blown, darkened, or discolored bulbs, or defective ballasts), replacing them with an energy efficient system is the only practical way to go. The above example is also only for one lighting fixture. Even small facilities will have many of these fixtures throughout a building. In this example, after 1.7 years the facility starts saving $ 37 per fixture per year.

Exit lights can also waste energy. Typical older exit lights have two 15 or 20 watt incandescent lamps. The new exit lights have either one 7 watt fluorescent lamp or two ½ watt Light Emitting Diodes (LED). Exit lights are on all the time (8760 hours per year). Two 15 watt lamps at $0.10 per kilowatt-hour will use more than $25 per year in power. An LED retrofit kit only costs about $25. Converting older style exit lights to LEDs will pay for themselves in about a year, and thereafter cost almost nothing to operate. Also, LEDs can last up to twenty five years.

Becoming aware of today's efficient lamps, ballasts, reflective fixtures, and control options available is the first step toward reducing your lighting costs. **Appendix E** explains these technologies further.

Clean Renewable Energy Sources

As the world population continues to grow, so does our need for energy, and all power sources impact the natural environment in one way or another. Some are sources of air pollution, others present waste, water or land issues. Currently, most of our energy is from fossil fuels (coal, oil, natural gas), which are limited, non-renewable and create air pollution. For the most part, renewable energy (sun, wind, water, biomass, geothermal) is produced without a large amount of air emissions and are virtually inexhaustible. However, the construction and maintenance of both renewable and non-renewable power plants may impact land, water and the surrounding environment.

Restructuring of the electric utility industry gives consumers the choice of who generates their electricity. Renewable energy typically costs more to produce, but with more consumer support, the costs of renewable power should go down. You can affect the availability and affordability of renewable energy by choosing an energy supplier who is more environmentally responsible.

Net Metering

Net metering programs allow the electric meters of customers with generating facilities to turn backwards when their generators are producing more energy than the customers' demand. Net metering allows customers to use their generation to offset their consumption over the entire billing period, not just instantaneously. This offset would enable customers with generating facilities to receive retail prices for more of the electricity they generate. Net metering is a simple and low-cost method to encourage direct customer investment in renewable energy technologies. The renewable energy industry supports net metering because it removes an economic disincentive for potential customers by increasing the value of the electricity generated by renewable energy technologies. Environmental groups support net metering because it promotes clean energy production.

Although generating electricity onsite from a renewable source is generally higher than for fossil fuels, when coupled with financing opportunities such as grants, discounts, and low interest loans, these sources can be affordable. Below are descriptions of some renewable and less polluting energy sources and possible uses at wastewater treatment facilities. For more information on energy efficiency and renewable energy contact the Department of Energy at www.eren.doe.gov, or, http://erecbbs.nciinc.com .

Wind

Early windmills of the 1800s produced mechanical energy to pump water or run saw mills. Today, wind energy may be used to generate electricity directly, power mechanical systems, or reduce a facility's energy costs when sold to a utility. Many utilities, such as Green Mountain Power Service in Vermont, have windfarms to generate electricity. Wind energy is currently cost effective for electricity generation only where the annual average wind speed is at least 12 mph. However, many municipal wastewater treatment facilities are located in a windy areas, such as a valley, the coastline, where wind may be a potential energy source.

For lagoon treatment systems that use surface aerators, it is possible to use the wind to directly power mechanical surface aerators to relieve existing aerators powered by the utility. The minimum wind speed for these systems is only 4 mph. The New Hampshire Department of Environmental Services (DES) is working with a community to demonstrate the effectiveness of wind powered surface mechanical aerators in a wastewater stabilization pond to save energy. The project is partially funded by a grant from the Governor's Office of Energy and Community Service. It began during the summer of 2000 and expects to last two years.

An alternative to using the wind to directly power a facility is to sell the wind generated energy to your utility to defray energy costs and continue to use the utility's power to operate the facility.

Solar

A variety of technologies have been developed to take advantage of solar energy (energy from the sun). Two major technologies are solar heating and cooling of buildings and photovoltaic conversion (converting sunlight into electricity).

Solar Heating and Cooling

Facilities that have good southernly exposures can take advantage of the suns energy. There are a few examples of wastewater facilities in New England using solar energy for heating.

One facility in New Hampshire uses a *solar wall* to help with its heating needs. The solar wall is based on simple passive solar heating principles. The system works by heating air with a south-facing solar collector—a dark-colored wall made with an energy absorbing material. As the sun strikes the collector hot air begins rising in the space between the solar wall. The heated air vents through the top of the wall and is distributed into the building. As heated air vents from the top of the wall, the cooler room air returns to the collector through vents near the bottom. The temperature is regulated by a thermostat which controls the vents at the top of the wall. Any additional heating needed at night or on cloudy days is supplied by the building's conventional heating system. During summer months, the sun is reflected off the collectors to prevent overheating.

A solar wall can be designed as an integral part of a new building or it can be added in a retrofit project. Expenses are usually minimal, because a solar collector requires little mechanical equipment.

Photovoltaic

Photovoltaic (PV) systems presents many possibilities and are the most versatile. PV systems became popular through the space program and are the primary source of power for satellites. PV cells have no moving parts, are easy to install, require little maintenance, do not emit air pollutants, and have a life span of up to twenty years. Because PV systems only work when the sun is shining, most systems are used in combination with batteries. Although the capital cost of PV systems has come down substantially, it is still high, and, except in certain circumstances, is not competitive with conventional grid power. Some instances where PV can be the better choice of power are:

* Power line extensions, even for short distances, will not be cost-effective considering the low loads to be carried;

* The remote location makes the costs or difficulty of transporting and storing diesel fuel prohibitive;

* Electrical needs are small, seasonal or remote.

Other industries have found applications where solar energy makes economic sense, such as, operating pumps for irrigation, air and water heating, and outdoor security lighting. Some of these application may also have possible uses at wastewater facilities. Some state agencies and utilities provide financial assistance for renewable energy projects.

Effluent Hydropower

Flowing water creates energy, which can be captured and turned into electricity. This is called hydropower. The energy of falling water is converted to mechanical energy by means of a turbine. The most common type of hydropower plant uses a dam on a river to store water in a reservoir. Water released from the reservoir flows through a turbine, spinning it, which in turn spins a generator which produce electricity. In the case of a wastewater treatment facility, the effluent is the flowing water. The energy produced depends on the distance the wastewater falls and the flow rate of the wastewater. The larger the flow and the further the wastewater falls, the more cost effective the system. In the late 1970s and early 1980s, two wastewater facilities in New England operated an effluent driven turbine, each with limited success. In **Appendix F**, the effluent driven turbine that was used at the Montague, Massachusetts wastewater treatment facility is briefly discussed. Although each facility is distinct, you can use the following formula to calculate the potential energy from an effluent driven turbine.

Potential Power (kW)= Head (feet) x flow(gpm) x 0.18(efficiency)
kWhr/yr = Power x 8760 hrs/yr

As with a wind system, power generated with an effluent driven turbine can be used directly or sold back to a utility. Your utility or state energy office may assist with financing or technical assistance for such a project.

Micro turbines

Micro turbines are adaptable low emission power generation systems. A natural gas turbine driven generator, coupled with an electronic control module, allows the unit to operate alone or connected to the grid. It produces electricity efficiently while emitting very low levels of air pollutants. They are low maintenance, can operate using a variety of fuels, and produces a clean oxygen rich heat exhaust that may be used as a heat source for the facility. **Appendix F** includes a preliminary evaluation of the application of a micro turbine at the Veazie, Maine wastewater treatment facility. For many facilities, the supply and cost of natural gas is critical to the cost evaluation. However, there are now several gas pipelines in New England, making gas supply more accessible. In the Veazie case, a pipeline is currently being constructed nearby, which presents the possibility of the wastewater treatment facility tying into the pipeline.

If your facility is evaluating options for future biosolids disposal, you may want to consider anaerobic digesters. The methane gas produced from digesters has long been valued as a fuel source at wastewater treatment facilities for heating and generating electricity. Similarly, landfills are a source of methane production that can be used as fuel. For further information about microturbines contact www.capstone.com .

Summary

Efficiency in motors, drives, lighting and other energy consuming technologies have come a long way in recent years. Older facilities that have not yet experienced an upgrade can definitely benefit from the newer technology. For motors operating more than 2000 hours per year, it makes sense to use only the most efficient motors available, because the cost of power in the Northeast outweighs the cost of a motor. If flow rates have changed over time your facility could benefit from a pumping system evaluation. Energy use in New England clearly has an important role in many of the environmental issues we face today. Through improved energy management and integrating renewable energy options where possible, you can reduce your energy costs and improve the environment by reduced air emissions.

Electricity is essential in virtually all our activities, and will become even more so as our population grows. Presently, one hundred-thirty pounds of air emissions are discharged to the atmosphere for every one hundred kilowatt-hours of energy generated. To maintain our current quality of life we will need cleaner and more efficient sources of energy. The power utilities continue to make improvements in their systems, which includes helping you make improvements at your facility. There are also many other organizations available to help you improve your energy use. You can help meet the growing energy needs and save money while preserving the environment.

APPENDIX A

Where to find Assistance

Financing

For those communities interested in reducing energy use and saving money there is a wide range of options available to help finance such project. Many state environmental agencies and energy offices have grants or loan programs to assist municipalities with infrastructure repairs/upgrades and energy improvements. Also, most utility companies have programs to help users reduce their energy demand through load management and energy efficiency. Your utility may also have other incentives or rebate programs for purchasing equipment that reduce energy and costs. **Appendix A-1** further explains the various financing options available for energy efficiency projects.

Energy service companies (ESCOs) fund eligible energy improvement projects through performance contracts or lease-purchase programs. Facilities repay these companies for their investments through a portion of the energy savings that resulted from the improvements. Most ESCOs have minimum requirements for projects, such as square footage affected. If your facility does not meet an ESCO's minimum requirements, other facilities can be added to the project, such as the school or police department, to make the project profitable.

If you lack time, staff or expertise to undertake an energy assessmen,t there are many professionals in the energy management business on which you can call for help. Below is a list of contacts that can help you as you begin to assess the energy opportunities at your facility.

New Hampshire Public Utilities Commission
8 Old Suncook Road
Concord, NH 03301
603/ 271-2431
email: Puc@puc.state.nh.us

Massachusetts Department of Telecommunications and Energy
One South Station Boston, MA. 02110.
617/305-3500
email: barry.perlmutter@state,ma,us

Maine Public Utilities commission
242 State Street -18 State House Station
Augusta, Maine 04333-0018
207/ 287-3831
email: maine.puc@state.me.us

Vermont Department of Public Service
112 State Street, Drawer 20
Montpelier VT 05620-2601
802/828-2811
email: vtdps@psd.state.vt.us

Rhode Island Public Utilities Commission
100 Orange St.
Providence, RI 02903
401/ 222- 3500

Connecticut Department of Public Utilities Commission Control
Ten Franklin Square
New Britain, CT 06051
860/ 827-1553
email: dpuc.information@po.state.ct.us
U.S. Department of Energy

Motor Challenge Information Clearinghouse
1-800-862-2086

Northeast Premium-Efficiency Motor Initiative
1-888-45MOTOR

NH Governor's Office of Energy and Community Service
57 Regional Drive
Concord, NH 03301-8519
603/271-2611

Massachusetts Division of Energy Resources
Legal Department
100 Cambridge St., Room 1500
Boston, MA 02202
617/ 727-4732

Connecticut Office of Policy and Management
450 Capitol Ave, PO Box 341441
Hartford, Connecticut 06134-1441
860/ 418-6297

Maine Energy Office-Energy Conservation Division
Department of Economic & Community Development
#59 State House Station
Augusta, Maine 04333-0059
207/ 297-2656

Rhode Island Energy Office
1 Capital Hill, 2nd Floor
Providence, Rhode Island 02908
401/ 222-3370

Energy Consulting
James K. Rogers
One Blacksmith Rd
Chelmsford, MA 01824
978/256-1345

Woodard and Curran
197 Loudon Road
Concord, NH 03301
603/224-0184

Bricar Engineering Associates
862 Farmington Avenue
Bristol, CT 06010

Association of Energy Engineers
www.aee.ncc.org

National Association of Energy Service Companies
www.naesco.org

U.S. Environmental Protection Agency
1 Congress St
Boston, MA 02114
617/918-1844

This list is not all inclusive.

APPENDIX B

Understanding Your Utility Bill

APPENDIX C

DEMAND-SIDE MANAGEMENT STRATEGIES

Where To Begin

The first step to an effective energy management program for your facility is to understand where your energy dollars go- Learn how and when each piece of equipment uses energy. How much energy goes to pumping, aeration, or lighting? What portion of the bill is for electrical energy consumption (kWh) versus peak power demand (kW)? Are demand charges ratcheted (monthly charges linked to the highest power draw over the preceeding year)? Is a power factor penalty, or kVA charge, levied? The answers to these questions tell you where to look for both energy and cost savings. **Appendix B** explains more about understanding your utility bill.

Conduct an Energy Survey

Energy surveys can vary in complexity, but a complete energy audit should answer these questions.

> * ***How much electricity is being used and at what time of day***? Can the use be reduced through changed operations.
>
> * ***How much is the utility charging for power*** and can it be reduced by using a different rate schedule?
>
> * ***How efficient is the equipment*** and is it worthwhile to improve the efficiency?
>
> * ***Can a change in the process result in improved energy use?***

The survey report should include recommendations for actions that will lead to energy and cost savings and should indicate the cost savings for each recommended action. A survey can be conducted by facility staff, if they have the time, or by contracting with a professional energy consultant.

There are three general levels to energy surveys. Ideally, you would want to start with the most basic survey and as opportunities are identified more thorough levels of analysis can be undertaken. If a consultant is used this may not be practical. However, it is advised that the facility at least conduct a desktop survey of their billing data before hiring a consultant.

A **desktop survey** principally involves an analysis of billing data. Understand your current electricity use (kWh) and your peak demand (kW). Calculate the energy cost of the facility in an understandable unit such as dollars per thousand gallons or per million gallons treated. This will establish a benchmark of energy use at the facility and can potentially identify some easy areas for energy reduction and cost savings. The facility staff can conduct this survey.

A **walkthrough survey** requires a brief inspection of the facility, all the equipment and methods of operation. Billing data is also analyzed. By comparing billing data to the daily operations opportunities for improving operations and thereby reducing energy and costs may be found. The rate at which energy is used will vary throughout the day, depending upon factors such as demand from the influent flow and biochemical oxygen demand (BOD) loading. Plot daily electrical load as a function of time for different plant loading conditions. Note which large equipment can be operated off-peak. Attachment C-1 will help you determine which equipment uses the most electricity. Examine all available rate schedules to determine which can provide the lowest cost in conjunction with appropriate operational changes. Many facilities have the experience to perform this type of survey but do not have the time. Many professional energy consultants are available to help.

A **detailed survey** requires an in-depth inspection and analysis of the facility. In addition to analyzing billing data and operations, all energy consuming systems are evaluated, including motors, pumps and lighting. In most cases a professional energy firm is contracted. To locate an energy company see Attachment A.

Reduce Peak Demand

For many facilities, a significant portion of their electric bill is for peak power demand. To help reduce the demand, look for opportunities to shift large electrical loads to off-peak time periods. For example, some plants can use system storage to ride out periods of highest load rather than operating pumps, or shifting high energy using operations, such as solids processing, to off- peak. Some facilities use alternative power, such as a generator, during the peak hours. Also, avoid running large intermittent pumps when operating the main pumps.

Equipment that must run during the peak period should be as efficient as possible. This would included the motors and pumps for main pump station, RAS and aeration system. Calculate the demand and monthly energy consumption for the largest motors in your plant (see Attachment C-1). You may be surprised at the results. A 25 hp motor may cost over $1,400 per month if run continuously. An increase in equipment or system efficiency may be cost effective. During on-peak periods, avoid using large equipment simultaneously: two 25 kW pumps that run only two hours each day can contribute 50 kW to the demand if run at the same time.

Improve Power Factor

Power factor is the relationship (phase) of current and voltage in AC electrical distribution systems and is a measure of how efficiently electrical power is being used. A high power factor indicates efficient use of the electrical energy while a low power factor shows poor energy use. Motors and other inductive equipment require two types electric power. One type is **Working Power**, measured by the kilowatt (kW). This is what actually powers the equipment and does the work. Secondly, inductive motors need magnetizing power to operate. The measurement of the magnetizing power, or **Reactive Power**, is the kilovolt-ampere Reactive (kVAr). **Reactive Power** does no work. The Working Power and the Reactive Power together make up **Apparent Power**, which is measured in Kilovolt-ampere (kVA). Power Factor is determined by dividing the Working Power by the Apparent Power (kW/kVA).

Under ideal conditions current and voltage are "in phase" and the power factor is 100%. If inductive loads (e.g. motors, transformers, ballasts) are present, power factors less than 100% , typically 80 to 90% can occur. The more inductive equipment a facility has the more reactive power (does no work) is required, and power factor decreases. Motors that run less than fully loaded also contribute to low power factor and waste energy because motor efficiency drops off below full load.

The power distribution system in buildings can be overloaded by excess (useless) current. Facilities that use a lot of power, such as treatment facilities, should consider correcting power factor to restore the kVA capacity of overloaded feeders within the building, and of course, to reduce the amount of your penalty, if you have one. If a charge is not assessed, the utility company builds this expense into its rate schedule. All customers share the burden. Under the system where specific charges are assessed for low power factor, consumers do have the opportunity to reduce their power bills by improving their power factors.

Analyzing your utility bills will usually reveal if you have a power factor problem. Even if the utility does not bill directly for power factor, a low power factor can raise your kWh and demand billing. This is because of real power is wasted by reactive power needs.

Possible Improvements

The two main causes for low power factor are: non-working reactive power (kVAr) of inductive motors, and inefficient motors. Some strategies for improving your power factor are:

**** Correct poor electrical contacts.*** Poor contacts contribute to electrical inefficiency and are the most cost effective to correct.

**** Survey for insulation and undersized conductors.***

**** Use the highest speed motor that an application can accommodate.*** Two pole (3600 rpm) motors have the highest power factor. Power factor decrease as the number of poles increase.

****Size motors as close as possible to the horsepower demands of the load.*** Motor efficiency decreases as the load decreases. Sometimes a smaller motor can be installed to handle lower loads or perhaps the motor should be resized (see Attachment G- resizing pumps). Also, older motors are less efficient than the motors available today.

**** Determine your facilities power factor*** and evaluate installing power factor correction capacitors. Capacitors are devices that store an electrical charge. In the case of inductive motors, they can store the needed reactive power to operate the motors. Capacitors are sized by the kVAr needed and cost about $30 per kVAr.

The greater your power factor the less reactive loading you will have and therefore less energy costs.

APPENDIX C-2

Energy Efficiency Opportunities

Below are some general areas that may improve energy use at wastewater treatment facilities and is included as information only. An energy assessment will determine which improvements are cost-effective and beneficial to a facility.

Aeration

Install automatic DO control on aeration system.

Variable Speed Drives (VSDs) on mechanical aerators or aeration blowers.

Convert from mechanical to diffused air aeration.

Convert from coarse bubble to fine bubble aeration.

Reduce air pressure when possible.

Consider anaerobic and deep well treatment technology.

Pumping - General

Install VSDs on pumps with long run hours and that are throttled or have Bypasses.

Run pumps in parallel.

Reduce pressures where possible.

Install improved efficiency motors/pumps/valves.

Downsize where oversized.

Lift Stations

Install VSDs on pumps.

Install improved pump controls.

Install improved efficiency pumps/motors/valves.

Vary well levels to reduce loads, especially during peaks.

Sludge Handling and Disposal

Install VSDs on sludge pumps.

Improve dewatering before incineration.

Install VSDs on incinerator fans.

Consider land disposal or pelletizing vs incineration.

Reducing Peak Load

Consider self generation during system peaks.

Schedule more pumping during lower cost periods.

Identify loads that can be reduced or interrupted.

Consider more storage.

Lighting

Turn them off, if not necessary.

Remove a lamp or two, particularly near windows.

Replace old or inefficient lamps with energy efficient models.

Replace old fixture with energy efficient models.

Install automatic light sensor switches.

APPENDIX D

Relating Centrifugal Pump Efficiency, Variable Speed Drives and Hydraulic Improvements to Energy Dollars

Steve Bolles Woodard and Curran
Don Casada Oak Ridge National Laboratory

Engineers, Operators, and Maintenance specialists all view their pump systems from different perspectives. The Engineer has traditionally been focused on pump equipment materials and sizing based on the most severe conditions that could be encountered at a facility. The Operator is typically interested in equipment flexibility, capacity and reliability. The Maintenance specialist concentrates on servicing the equipment, ensuring spare parts are readily available, proper installation and refurbishment, and of course pump system reliability. Even though many of us are focused on one segment of pump systems, we have all picked up ideas and practical knowledge from each of these areas.

The continuous pressure to reduce costs with less resources has forced many of us to learn more about pump system mechanical and electrical system efficiencies, and how to evaluate our pump systems to ensure we have done everything possible to reduce operational costs. The prime component of these operational costs is often the cost of energy.

This paper discusses the performance characteristics of the basic components of pumping systems. It also relates some factors that affect the components individually as well as how the individual component efficiency is interrelated with the other components.

Evaluating a pump system to increase system efficiency and reduce energy costs, can be segmented into the following major categories:

- ***Energy Costs and Utility Rate Structures***
- ***Hydraulic System Efficiency***
- ***Mechanical Efficiency***
- ***Electrical Efficiency***

Before even beginning the process of evaluating each of the above categories, the most important step is often to get the "big picture" on your pumping operation. Some of these questions may include:

Is a plant expansion or major process change expected soon? If this change is three years down the road it may still be worth making operational changes that can be implemented in the short term.

Can the process be changed to eliminate the need for pumping or reduce the flow rate or head? (In some cases a piping change will allow gravity flow for a process where a pump was previously specified)

Do the system flow rate/head requirements change with time? Are the changes in flow requirements continuously variable and spread over a relatively broad range, or at a few discrete flow rates?

It may seem like the above questions are obvious, however, it is surprising how often these issues are overlooked. One approach that is often used in characterizing system requirements is the development of a flow rate requirement[1] vs. time curve, sometimes called a flow duration curve. An example of duration

---

[1] It is important to make the distinction between system *requirements* and actual operation, in the case of pre-existing systems unless there is confidence that the two quantities are the same.

curves for three different systems is shown in Figure 1. The total flow required (i.e., the area under each curve) is the same for the three systems, but the distribution is obviously quite different. This type of curve is a good starting point for overall system analysis. Further consideration, such as the relationship between system flow and head requirements is needed to fully understand system requirements and optimal design. But even a casual review of the three duration curves shown in Figure 1 reveals that the kind of pumping configuration that is suitable for System A (a single-size pump, selected to operate efficiently at the constant flow requirement) would be less than optimal for either System B or C.

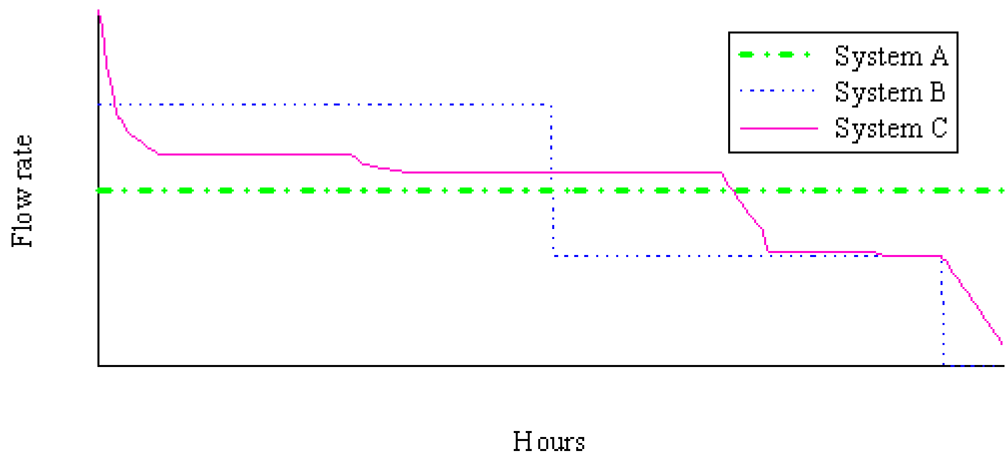


Figure 1. Example flow duration curves

Energy Costs and Utility Rate Structures

One of the first areas that deserves investigation before focusing on the efficiency details of a pump system is to understand energy rate schedules and how the cost of energy is determined at a facility.

Although many industries produce their own energy at very reasonable rates, most facilities purchase their energy from the local electric utilities. Typical utility energy costs include a consumption charge (kWh) and a demand charge (kW or kVA), and in some cases, a power factor penalty. Energy consumption charges range from 3 to 6 cents per kWh in the South and Midwest to 8 to 12 cents per kWh in the Northeast. Energy demand charges range from $4.00 up to $25.00 per kW of demand. For a 100-hp water pumping station that operates continuously, a sample monthly energy cost calculation may be as follows:

Element	Monthly value	Per unit cost	Cost ($)
Service charge	Fixed fee	$35/month	35
Energy use	57,600 kWh	$0.08/kWh	4,608
Peak demand	90 kW	$10/kW	900
Total			**5,543**

Note that there are other costs that are sometimes involved, such as fuel charges and power factor penalties that are not included here. As indicated in this example, demand cost can be 20% of the total energy bill and should always be considered when calculating savings.

An important consideration in energy *cost* reduction is the option of applying Time-of-Use Electric Rates. Although the example in Table 1 shows a constant consumption rate of $0.080/kWh, some electric utilities reduce the cost of energy during off peak hours (typically evenings and weekends). Municipal water system that have been designed with adequate storage and efficient use of "pressure zones" can often pump only at night to replenish water storage tanks and rely on water storage capacity and elevation pressure to provide water service during the day. It is important to distinguish between overall energy consumption and energy costs here, since pumping at much higher capacity in off-peak hours (and consequently at lower capacity during on-peak hours) may actually require more energy consumption than if the system flow rate was maintained relatively constant.

Hydraulic System Efficiency

An important aspect of evaluating pump systems is to understand how the system is operated. This includes reviewing the system surrounding the pump rather than just the pump and driver. Some of these considerations include:

- What flow rate and pressure are *required* for the process? Is more of either being provided than is necessary?
- How is the pump being controlled? Can level or pressure setpoints be adjusted to higher or lower values?
- Are there restrictions in the piping system (e.g., throttled valves, pressure reducing valves, unneeded or oversized check valves, excessive elbows, corrosion and scale build-up in the piping system)? In a similar vein, have the system requirements changed significantly so that the existing pipe velocity is well beyond what was originally anticipated?
- Are multiple pumps operating in series or parallel being operated efficiently with control systems?

Answers to the above questions often provide the most cost-effective improvements that can reduce pumping energy costs by simple operational adjustments or piping improvements.

It is particularly important to first search for savings in the hydraulic system, since savings achieved at the system level are amplified at the pocketbook level. This is because the pump and motor are not 100% efficient; so for every horsepower reduction in fluid power requirements, there is about a 1.4-hp reduction in electrical power requirements, even for systems in which the pump and motor are operating efficiently.

It is useful to develop system head-capacity curve(s) for the most common system alignment condition(s). This curve is useful for several reasons:

20) It, in conjunction with the pump head-capacity curve, defines where the system will operate. In order to gauge the effects of system or pump changes on overall performance, such a curve is essential.
21) It provides a baseline against which to compare future system performance. As the system ages and when components are replaced, the baseline curve can be used as a reference value from which potential savings can be estimated.
22) It helps identify situations where variable speed drives may be most effective (systems that are dominated by frictional head) or least effective (systems that are dominated by static head).

To help illustrate the merits of developing and trending system performance curves, an example system head-capacity curve (with no static head) is shown in Figure 2. The same curve, along with a second curve representing the same system after scale buildup in the piping is shown in Figure 3. To maintain a constant flow rate of 2500 gpm, an increase of system head of about 31 feet must be overcome. The increased head of 31 feet corresponds to an increase in hydraulic power (assumed fluid specific gravity = 1.0) of almost 20 hp, which is about 25% more than was required in the new, clean system.

Assuming a constant combined pump and motor efficiency of 70%, the frictional losses would translate into an electrical power requirement of about 21 kWe. If the system was operated continuously at this condition, and the per unit energy cost of electricity was $0.08/kWh, the annual cost of the increased friction would be almost $15,000.

Changes in the system curve affect the pump operating point (which in turn, affects the motor operating load), so the pump and motor efficiency would not, in a real-world application, remain fixed. But this simplified example helps to illustrate the merits of understanding and trending system performance.

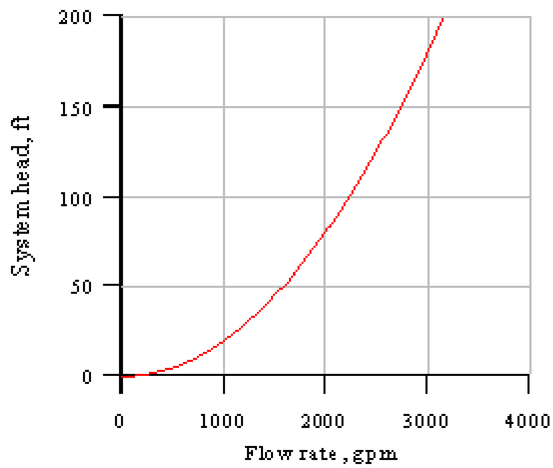


Figure 2. Example system head-capacity curve

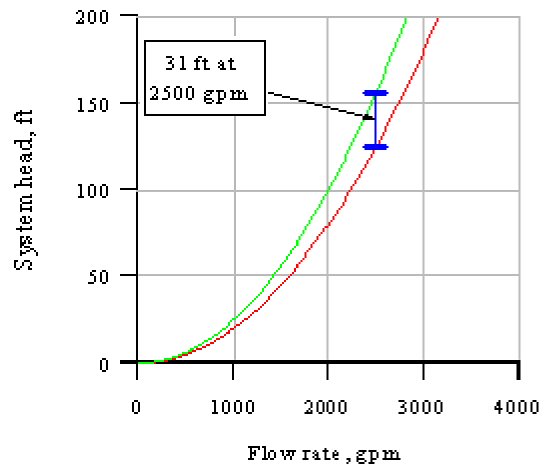


Figure 3.Change in system curve with increased friction

Pump Efficiency
After developing an understanding of system operation and the operational cost components of your pump system, the mechanical/hydraulic efficiency of the pump should be investigated. One of the first places to start is to obtain a copy of manufacturers pump curve. Possible sources of pump curves are:

1) a test facility certified performance curve for the specific pump in question,
2) ***an in-situ performance curve (if good quality instrumentation is used, this is a preferred method, since it captures the actual motor and pump characteristics),***
3) generic performance curve from the manufacturer's catalog, or
4) software packages that include manufacturer curves.

The performance curves will provide a graphical understanding of the relationship of flow rate, head, efficiency, and shaft input power of the pump. In the case where an in-situ performance curve is generated, the electrical input power to the motor replaces the shaft power. An example set of performance curves for a pump that might be used in the system shown in Figures 2 and 3 is shown in Figure 4.

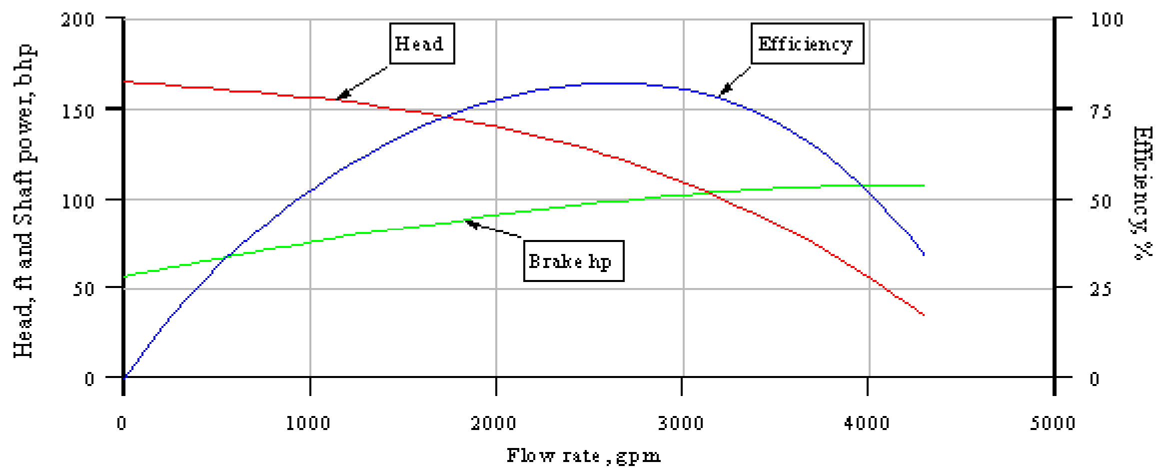


Figure 4. Example pump performance curves

A couple of key questions to be answered when considering pump performance curves are:

1) Is the pump operating reasonably close to its best efficiency point (BEP), at each required operational head and flow condition?

2) Has pump or system performance changed over time (for situations where a baseline set of pump performance curves are developed and compared against subsequent performance data)?

Once both the pump and system performance curves are available, the system and pump curves can be jointly plotted to identify the operating point(s). This exercise is especially important in answering the second question above.

Figure 5 shows the head-capacity curves for the system(s) and pump from Figures 3 and 4. The shift in flow rate *and* head that occur due to the increased frictional losses in the system are annotated. Figure 6 demonstrates possible pump performance degradation in a fixed system. The key point to be made is that baseline measurements of both pump and system performance characteristics provide the reference value against which subsequent measurements can be evaluated and thereby help in the identification of corrective actions.

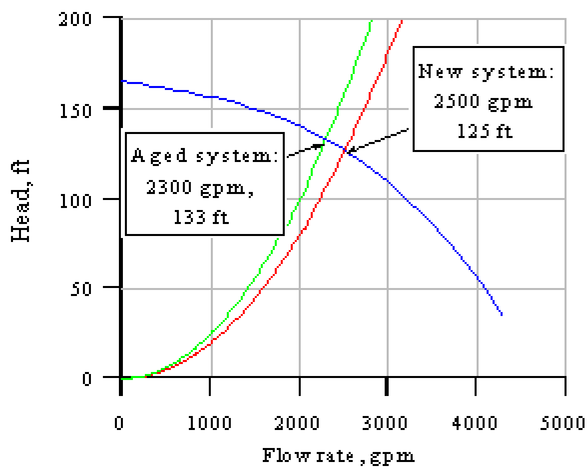


Figure 5. Fixed pump with system degradation

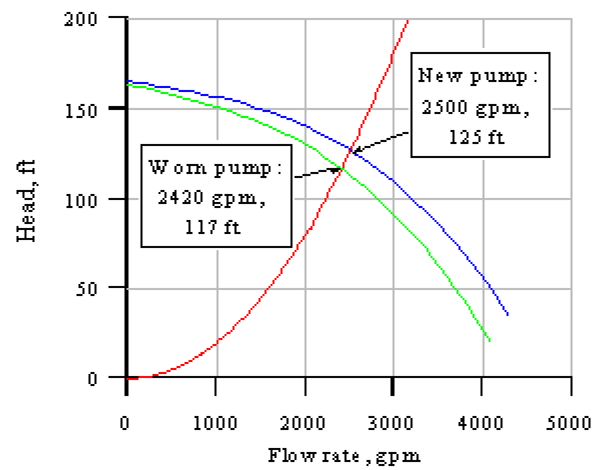


Figure 6. Fixed system with pump degradation

In cases where multiple pumps are operating in parallel or in series, graph paper or a pump-modeling program is useful for developing composite pump curves.

If the existing pump is operating well away from its BEP flow rate, there is prima facie evidence that efficiency and operational cost reduction opportunities exist. The suitability of alternative courses of action depends on a variety of factors, including:

1) the range of flow requirements, and whether the flow varies continuously or in discrete steps;
2) the distribution of the system static and frictional head components;
3) the distribution of time operating at the various flow rates;
4) whether there is evidence that the pump is degraded.

Electrical Efficiency

The electrical efficiency of a pump system is, in essence, the motor output mechanical shaft power divided by the power measured at the utility meter. It includes the electric motor, switchgear, and supply leads, and where applicable, variable speed drive, filters, and transformers. Overall, the efficiency of these electrical components is usually very high. While there may be opportunities to gain a few efficiency points in the electrical components themselves, the primary improvements usually achieved in the electrical area are to improve the efficiency – or, perhaps more importantly reduce the power requirements of either the pump or the fluid system.

Typical motor performance efficiency vs. load and power factor vs. load curves for two motor sizes are shown in Figures 7 and 8. The curves shown are for four-pole, energy efficient ac-induction motors.

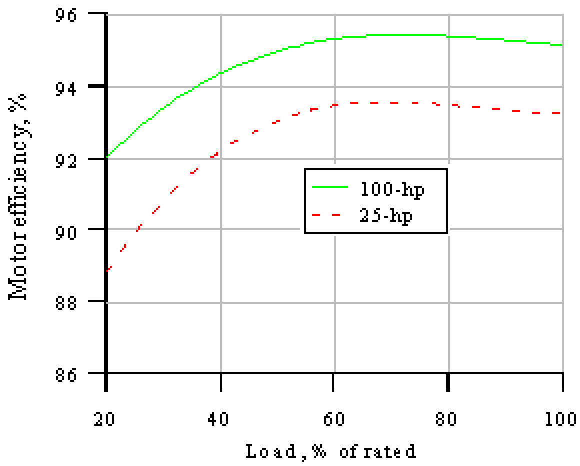


Figure 7. Typical motor efficiencies vs. load

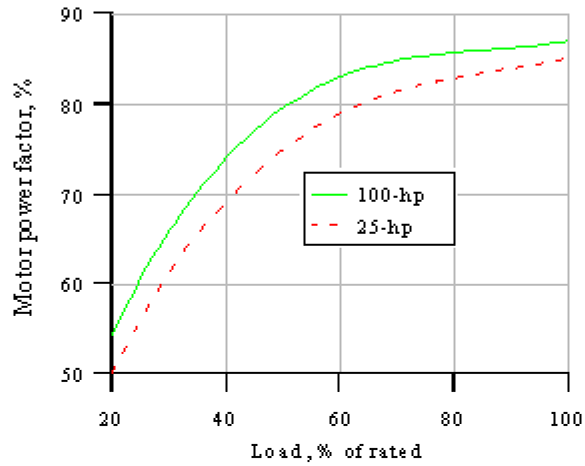


Figure 8. Typical motor power factors vs. load

An important point to recognize from Figure 7 is that efficiency for induction motors is essentially constant over the normal load range. It is only if the motor is extremely lightly loaded that sizing is an issue. In fact, if a power factor penalty is part of the rate structure (either explicitly or implicitly, based on historical experience), the low power factor at light load might be a more significant cost factor than the slight reduction in efficiency.

When an adjustable speed drive is used, the motor speed can be reduced to accommodate the system flow requirements with reduced energy consumption over these alternative means:

1) Not controlling flow at all that is, running the system at a higher flow rate than is necessary to meet the system requirements,
2) Controlling flow in a batch mode that is, starting and stopping the pump for limiting conditions, such as when filling or depleting a tank or reservoir,
3) Controlling flow by valve throttling, or
4) Controlling flow rate by recirculating a portion of the flow.

Of course, like any other active component, the drive efficiency is not 100%. Figure 9 shows motor, drive, and combined efficiency for a modern pulse width modulated drive operated at rated speed conditions (on a two-pole, 50-hp motor). The motor efficiency alone, when driven directly from the power supply (i.e., without the drive) is also shown for comparison. As can be seen, the drive efficiency is in the upper 90-percent range. The drive also causes the motor to operate at a slightly lower efficiency than when the motor is driven directly across the line.

Figure 10 shows the same motor efficiency curve as Figure 9, but for the combined drive and motor curve, uses data that represents centrifugal loads (i.e., output power is proportional to the speed cubed).

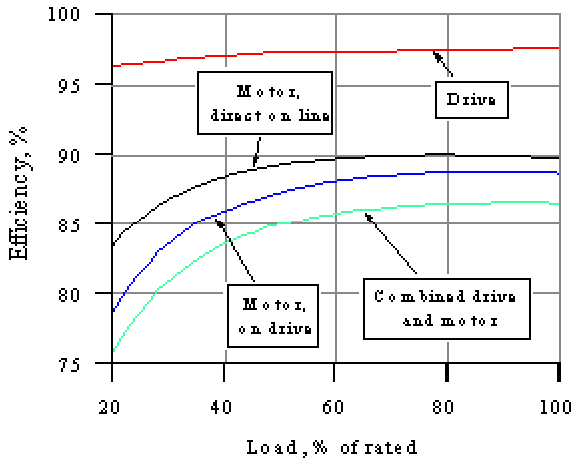


Figure 9. Motor and adjustable speed drive efficiencies at rated speed

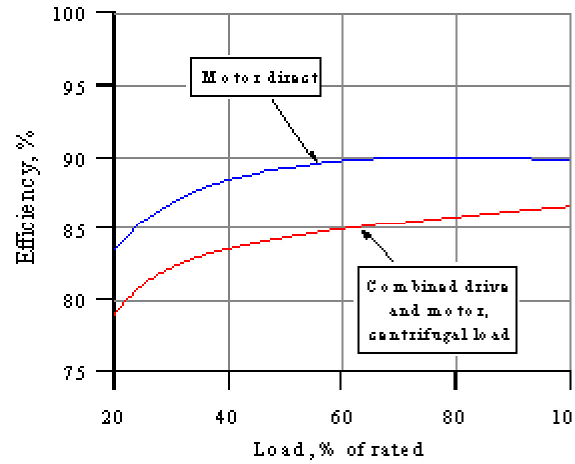


Figure 10. Motor (rated speed) and adjustable speed drive (centrifugal-type load speeds) efficiencies

But simply considering efficiency alone doesn't capture the essence of variable speed drives. The real saving derives from the drop in power that accompanies speed reduction. For centrifugal loads, such as pumps, the shaft power is approximately proportional to the cube of the speed. Figure 11 contrasts the difference in shaft power between fixed and variable speed driven when the pump whose performance curves are shown in Figure 4 is used in the system whose head-capacity curve is shown in Figure 2. The shaft power for the variable speed case was calculated using the pump affinity laws (discussed below).

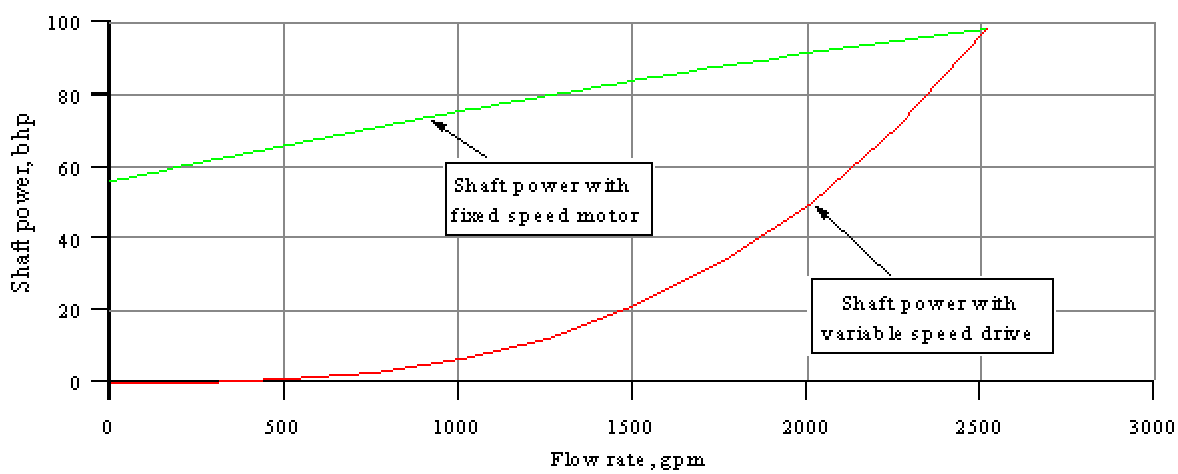


Figure 11. Shaft power requirements for a fixed and variable speed driven pump

Overall Pumping System Calculations and Field Measurement Considerations

Pumping system electric power and energy consumption can be calculated as follows:

$$P = \frac{Q\,H\,\gamma}{5310\,\eta_p\,\eta_m\,\eta_s} \quad \text{and} \quad E = \frac{Q\,H\,\gamma\,T}{5310\,\eta_p\,\eta_m\,\eta_s}$$

Component	Abbreviation	Units
Power	P	kW
Energy	E	kWh
System flow rate	Q	gpm
System head	H	ft
Fluid specific gravity	γ	Dimensionless
Run time	T	hours
Pump efficiency	η_p	Dimensionless fraction
Motor efficiency	η_m	Dimensionless fraction
Electrical supply efficiency	η_s	Dimensionless fraction

Since it is none of the efficiency values can be practically measured in the field, the efficiency terms can be combined to a single overall value, η_T, resulting in the following relationships:

$$P = \frac{Q\,H\,\gamma}{5310\,\eta_T} \quad \text{and} \quad E = \frac{Q\,H\,\gamma\,T}{5310\,\eta_T}$$

Some notes regarding the field measurement of these parameters:

1. In many cases (for example, where ambient temperature water is the pumped fluid), the specific gravity can be assumed constant; but it is important to note that other situations, such as where variable consistency slurries are being pumped, the specific gravity should be measured.
2. By definition, the head and flow rate for the system and the pump are equal, since the intersection of the pump and system head-capacity curves define the operating points for both. Measurement of the pump head requires that suction and discharge pressure measurements be made (and gages referenced to a common elevation). True pump head measurement also requires an accounting of differences in suction and discharge velocity heads, but as a general rule in field measurements, the differential velocity head can be disregarded because it is such a small component of head.
3. The two parameters that are usually most readily measured are pump head and electrical input power. If an *accurate* pump performance curve is available, the head can be used to graphically determine flow rate. It is important to emphasize the word *accurate* here, since it is not unusual for pump performance to deviate from generic manufacturer curves; furthermore, it is all too commonly found that the user doesn't possess even a generic performance curve.
4. It is important to measure rotating speed (e.g., with a portable strobe light). Pump performance curves (even certified curves) are usually performed at a particular speed. The test speed may be one or two percent different from the actual speed. This has a significant impact, and the performance curve needs to be adjusted for actual speed conditions (see discussion on pump affinity laws below).
5. When the only two parameters that can be measured are head and motor power, and a generic pump performance curve is available, there is a great deal of value to using these two measurements to do a confirmatory cross check. For example, use the measured pump head and the head vs. capacity curve to estimate the flow rate. Next, estimate electrical train efficiency. Unless a variable speed drive is being used, the motor is the only component that usually needs to be considered. On newer motors, the motor nameplate will include a NEMA nominal and/or guaranteed motor efficiency. Multiply the measured motor input power by the estimated motor efficiency to estimate shaft power. Then compare this value to that derived for the estimated flow rate the power vs. capacity curve. If there is a significant difference, further consideration is warranted. Some possible reasons are:
   a. Particularly if the measured power suggests that the pump is not as efficient as the curve indicates

(i.e., if the measured power is greater than the curve-based power at the estimated flow rate), it may be safe to assume that the pump is simply not operating at the manufacturer curve efficiency. This could be due to poor pipe layout (and resultant fluid geometry) in the field; it could also be the result of pump wear.

b. If the reference curve is simply a generic performance curve for the particular pump model, it is important to recognize that there may be significant variation in performance from pump to pump.

c. The head or power measurements (or estimated motor efficiency) were erroneous. If permanently installed pressure gages were used for the head determination, their accuracy should be verified. In the authors' experience, field gages often go for years without being calibrated or even checked. If at all possible, temporary test gages known to be in calibration should be used if at all possible.

It is usually necessary to apply the pump affinity laws to account for differences in actual operating speed and the speed at which the pump curves were developed. The pump affinity laws are as follows:

$$Q_2 = Q_1 * \left(\frac{N_2}{N_1} \right) \qquad H_2 = H_1 * \left(\frac{N_2}{N_1} \right)^2 \qquad P_2 = P_1 * \left(\frac{N_2}{N_1} \right)^3$$

where Q = flow rate, N = rotational speed, H = head, and P = power. The subscripts 1 and 2 represent two different speeds.

Another form of the affinity laws relates to impeller diameter, D:

$$Q_2 = Q_1 * \left(\frac{D_2}{D_1} \right) \qquad H_2 = H_1 * \left(\frac{D_2}{D_1} \right)^2 \qquad P_2 = P_1 * \left(\frac{D_2}{D_1} \right)^3$$

The subscripts 1 and 2 represent two different impeller diameters. The impeller diameter affinity scaling relationships have proven useful in some field-based measurement experiences in that the impeller diameter used as the basis for the performance curves can be modified iteratively to a point where the curve-based flow estimates from measured head and power are in agreement.

Opportunities for Improving Pump System Efficiency

After a preliminary review of the pump system as been performed, some quick calculations can be performed to identify the magnitude of savings that each opportunity may provide prior to more extensive field testing. Some examples of preliminary calculations may include:

Using the pump equation shown above and the manufacturers pump curve to identify the impact of lowering the TDH on a system by raising the level in the pump suction (e.g., raising the average level of the wetwell in a waste water application), reducing pressure on the discharge side of the pump, or decreasing the piping system head losses.

Using the affinity laws to determine how a reduction in flow by shaving the pump impeller size or reducing the speed of a variable speed drive will effect energy use.

Performing some preliminary estimates of savings is useful prior to a detailed evaluation to understand what kind of testing should be performed.

As each pump system is reviewed, several potential improvements may provide savings in one area and reduce efficiency in other areas. One of the most common improvements that this occurs is when variable speed drives are applied.

The primary advantages of AC variable speed drives (also called VSDs, VFDs or ASDs) is to control the pump flow rate by adjusting pump motor speed. Figure 12 illustrates the change in pump head-capacity curves as motor speed is changed (using the affinity laws).

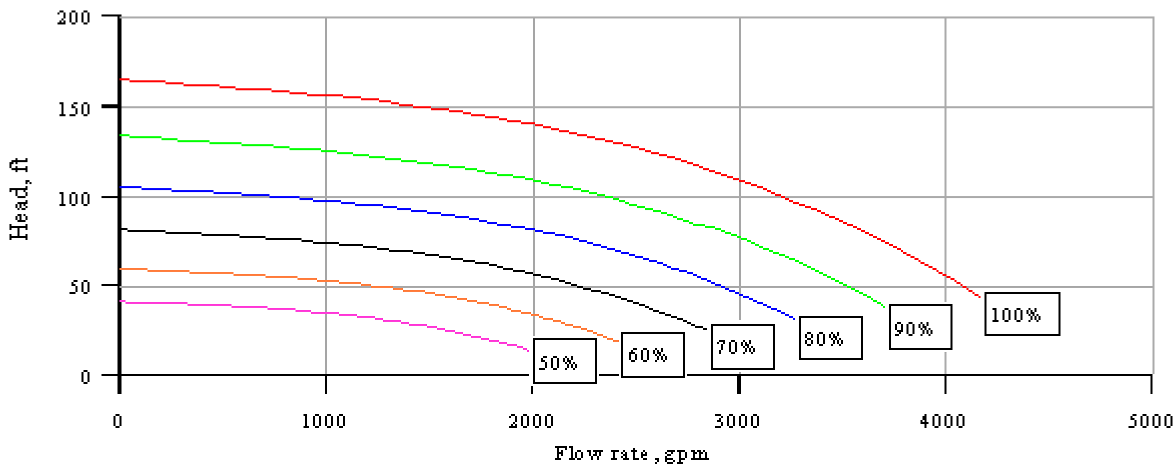


Figure 12. Head-capacity curves at varying speeds

It is important to understand, however, that the change in actual flow rate doesn't necessarily follow the affinity laws in fact it only follows the affinity law scaling for systems with no static head. This can be illustrated by overlaying two system curves on the series of pump curves, as shown in Figure 13. For the system with 100 ft of static head, reducing motor speed to 80% of nominal causes a reduction in flow rate to about 25% of that for full speed. This is in stark contrast to the all frictional (no static head) system, for which operation at 80% speed results in the flow rate dropping to 80% of that at full speed.

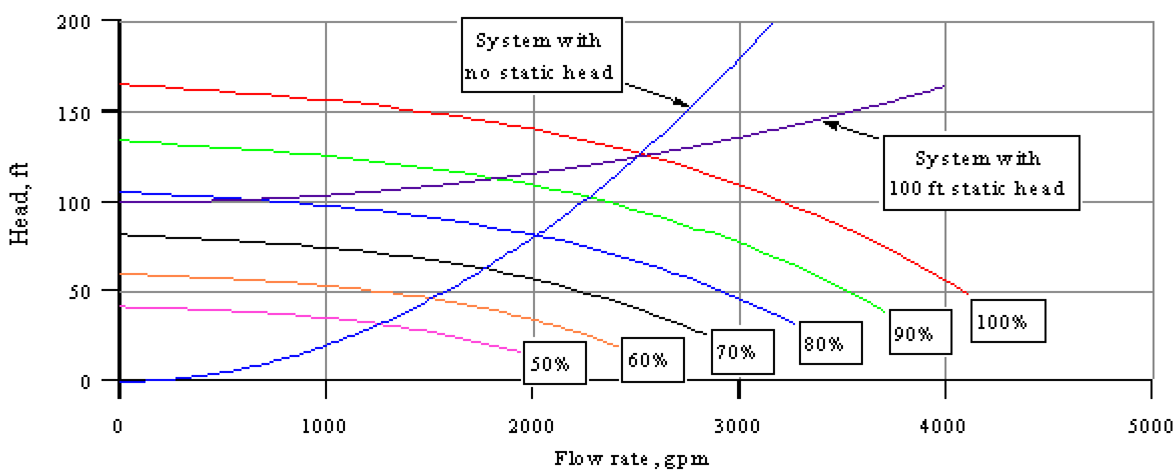


Figure 13. System and pump head-capacity curves at varying speeds

Several factors that should be weighed when considering application of drives are:

1) A fundamental requirement for considering variable speed drives should be that flow (or in a more limited sense, head) requirements change over time. If the system flow and head requirements are essentially fixed, efforts should concentrate on ensuring a properly sized pump (which should also be a consideration, regardless of whether a drive is employed).
2) The greater the proportion of the system head that is static, the less effective will be the variable speed drive. This is particularly true if the flow requirements vary significantly. Parallel pumps are, on the

other hand, most effective in systems that are dominated by static head. Parallel pumps need not all be identical; in fact there are some systems, such as waste treatment plant applications, where a small pump could meet system requirements 80-90% of the time, and supplemented by a parallel, larger pump for the occasional higher flow condition.

3) The pumps must operate enough hours during the year to justify applying VSDs (when based on a simple payback, a pump station with multiple pumps may only have the lead pump equipped with a VSD).
4) In situations where there is significant static head, the effective range for a variable speed driven pump can be increased by selecting the pump such that the pump operating point is to the right of (i.e., greater than) the BEP when operating at the highest anticipated flow requirement. This allows the pump efficiency to initially increase as speed is reduced.
5) The motor and electrical system should be verified to be suitable for drive applications. This is particularly important if a VSD is being added as a retrofit.
6) If a variable speed drive is being retrofitted to systems with switch-based controls, such as a float-type level control system that causes the pump to be started or stopped at distinct levels, continuously variable instrumentation, such as a level indicator, will need to be added for control purposes.
7) In a similar vein, systems that currently employ control valves with automatic valve positioners can usually be more easily retrofitted by using the existing valve positioning signal source as the controlling signal. It might be noted that valves that are normally significantly throttled are a good first indicator of a system for which a drive may be effective.

Evaluating Pump Systems

Evaluating pump systems begins with an understanding of how the pump is operated. Often it is useful to assemble a table with several flow intervals that can be used to determine how often the pump operates at various flows. Several data collection or estimating options for each aspect of operation are shown in Table 1.

Table 1. Measurement considerations

	Method	**Notes**
Flow rate	Estimate flow rate from measured head and/or power	- Depends on accurate pump performance curve; - For many pumps, shaft power varies relatively little with flow rate; - Motor efficiency must be assumed.
	Measure, using permanently installed flow meter	- Usually preferred; calibration/accuracy must be verified
	Measure, using portable flow meters, such as ultrasonic	- Ensure that a proper flow profile exists (suitable length, particularly downstream, of elbows or other flow disturbances)
	Calculate, using thermodynamic flow meter	- Accuracy Reduced for Low Head Pump Systems
	Measure, using pump down test	- Head changes must be accounted for.

	Method	**Notes**
Head	Estimate head from of measured flow and/or power	- Depends on accurate pump performance curve; - For many pumps, shaft power varies relatively

		little with flow rate; - Motor efficiency must be assumed.
	Estimate pressure loss from components, pipe data	- Not verified with field data; large uncertainties, particularly with older systems, unless most of the head is static
	Measure using suction and discharge taps	- Gage accuracy must be verified. Use of portable test gages is recommended. - If significant loss components are between the pump and the pressure gage, an estimate of the associated head loss must be made.

	Method	Notes
Efficiencies	Estimate motor efficiency from nameplate, manufacturer data, or software sources	- Although there may be some inaccuracy, the errors will generally be small relative to other error sources
	Estimate electrical system efficiency from power measurements on each side of transformer, VSD, etc..	- Accuracy of many power meters is suspect when used between the VSD and motor. Monitor on the line side of the drive to minimize this problem. - Measurements on the high side of transformers (above 600V) will require the availability of already installed instrumentation.
	Calculate overall pump and electrical train efficiency using measured input power, head and flow rate	- Accuracy depends on individual measured component accuracies. This is the authors' preferred approach.

Table 1. Measurement considerations (continued)

	Method	Notes
kW	Calculated from head and flow rate measurements, pump performance curve and assumed electrical efficiencies	- Not recommended unless there are no alternatives.
	Estimated from measured current	- Can be reasonably accurate, provided that representative motor performance curves are available.
	Estimate from measured speed	- Not recommended. Errors can be particularly large on newer, low-slip motors.

After selecting the methodology of data collection, a table can be developed for each flow interval as shown below in Table 2. Only 5 flow intervals are shown, however each pump system reviewed may have more or less intervals depending on the application

Table 2. Flow Interval Data Collection Table

Interval	Pump Flow	Head	Pump	Motor	Calculated	Annual	kWh

	(gpm)	(ft)	Efficiency	Efficiency	kW	Hours of Operation
1						
2						
3						
4						
5						
Totals	**--**	**--**	**--**	**--**	**--**	**8760**

From the collected data, it is often useful to plot head and flow measurements from field collected data compared to the original pump curve data. This can be done with pump modeling programs, or with the graphing option of spreadsheet programs. This modeling is especially useful to determine how output and efficiency performance is effected in a multiple pump system.

Examples of Cost Saving Opportunities

Case Study A: Municipal Wastewater Pump System

Ten 3,500-hp pumps equipped with A.C. variable speed drives were evaluated to identify potential areas of savings. A review of pump system operation revealed the following:

- The suction tank (wetwell) average operating level could be increased to reduce total system head
- Multiple pump system efficiency could be improved with automatic control systems

A review of the pump system operation provided the following data:

Existing Pump Operation (one flow interval shown over 36 performed for full analysis of this system)

Pump Type:	Vertical single stage centrifugal pumps
Total Head (TDH):	85 ft.
Flow:	110 million gallons per day (76,000 gpm)
Pump Efficiency:	90% (from certified curve)
Combined motor and electrical supply efficiency:	92% (from electrical calculations)

The product of the pump and combined electrical efficiencies is 82.8%. From the pump equation, electrical power, in kW (P) can be calculated with the following equation:

$$P = \frac{Q\,H\,\gamma}{5310\,\eta_T}$$

For one of the existing flow intervals:

$$P = \frac{76{,}000 \text{ gpm} * 85 \text{ ft} * 1}{5310 * 0.828} = 1.47 \times 10^3 \text{ kW}$$

Proposed Operation

The potential of raising the level on the suction side of the pump by 2 feet provided an excellent opportunity to reduce the total head on the pump system. Although the adjustment seems small, the ability to ramp down the variable speed drive slightly to produce the same flow at a lower drive speed provided the following savings (pump and electrical efficiencies did not change significantly):

$$P = \frac{76{,}000 \text{ gpm} * \boldsymbol{83} \text{ ft} * 1}{5310 * 0.828} = 1.43 \times 10^3 \text{ kW}$$

Power, energy, and cost savings were calculated:

Reduction in motor power:	0.04×10^3 kW = 40 kW
Reduction in annual energy usage[2]:	40 kW * 8760 hours/year = 3.5×10^5 kWh
Annual cost savings:	3.5×10^5 kWh * $0.070/kWh = $24,500

This simple control system adjustment did not require an investment and paid for itself immediately.

Case Study B: Municipal Water System

An existing 200-hp finish water pump (with the motor driven directly off the line) was reviewed to determine the cost effectiveness of repairing or replacing the existing pump. Repair estimates to refurbish the worn pump was approximately $10,000.

A review of the pump system provided the following generic nameplate information:

Pump Type: Split case horizontal pump		**Design flow rate, head:**	1,300 gpm, 415 ft
Pump efficiency from curve:	70%	**Nameplate motor efficiency:**	94% (2-pole motor)

Other electrical system losses were assumed negligible.

The nameplate pump efficiency of 70% was compared with information included in Hydraulics Institute (HI) standard ANSI/HI 1.1-1.5-1994, which indicated an achievable efficiency of 80%. To determine the potential savings of replacing the pump with a higher efficiency unit, the 70% pump efficiency was confirmed by taking flow, head and kW measurements (electrical efficiency losses were assumed as noted above). Rearranging the pump curve confirmed the efficiency noted on the pump curve as shown below:

$$\eta_p = \frac{Q H \gamma}{5310 P \eta_m}$$

The motor power, measured at the nameplate conditions, was 155 kW. The pump efficiency was then estimated to be:

$$\eta_p = \frac{1{,}300 \text{ gpm} * 415 \text{ ft} * 1}{5310 * 157 \text{ kW} * 0.94} = 69\%$$

After a review of energy rate schedules and system configuration, the pump efficiency was reviewed in more detail to determine if other manufacturers could provide better efficiency at the some flow conditions. Based on a few phone calls, several pumps with the same configuration were found that could achieve the same flow and head at 80% efficiency (which, incidentally, was consistent with the HI standard noted above). Combining this improved pump design with a premium efficient motor (96% efficiency) produced the following:

$$P = \frac{Q H \gamma}{5310 \eta_p \eta_m}$$

$$P = \frac{1{,}300 \text{ gpm} * 41.5 \text{ ft} * 1}{5310 * 0.80 * 0.96} = 132 \text{ kW}$$

---

[2] To simplify this example, the operating condition is assumed to be constant throughout the year.

Reduction in motor power:	25 kW
Annual kWh Savings:	25 kW * 8760 hours/year = 219,000 kWh
Annual cost savings:	219,000 kWh * $0.090/kWh = $19,710 annual savings

This project paid for itself within 2 years (not including the avoided $10,000 maintenance expense on the old pump).

Summary

It is our hope that this paper has successfully presented useful information to help operators, engineers and maintenance staff identify cost saving opportunities for their pump systems. As demonstrated in the case studies above, some quick calculations and data collection can help discover improvements that are cost effective and help justify investing in new pump equipment, control systems and efficient electrical systems.

APPENDIX E

Lighting

As a nation, we spend about one-quarter of our electricity budget on lighting, or more than $37 billion annually. Yet much of this expense is unnecessary. Technologies developed during the past 10 years can help us cut lighting costs 30% to 60% while enhancing lighting quality and reducing environmental impacts.

The greatest energy savings will occur by replacing existing fluorescent light systems with more energy-efficient equipment such as improved fluorescent lamps and electronic ballasts, which increase lighting efficiency by up to 25 percent. There are other improvements to consider as well but their usefulness depends on the type of facility and the use of the facility.

Fluorescent Lamps

The light produced by a fluorescent tube is caused by an electric current conducted through mercury vapor which illuminates a phosphor coating on the bulbs. Fluorescent lighting is about 3 to 4 times more efficient than incandescent lighting and last about 10 times longer. Although fluorescent lamps are generally energy efficient, there are new, even more efficient lamps that use better electrodes and coatings than do older fluorescent lamps. They produce about the same lumen output with substantially lower wattage.

Older, but still common , 40-watt T 12 (4 feet) and 75-watt T 12 (8 feet) lamps can be replaced with energy-saving T 8 lamps of 34 watts and 60 watts, respectively, without sacrificing light output. The older style T 12 lamps are 1.5 inches in diameter, and the newer T 8 lamps are 1 inch in diameter. The T 8 lamps do put out slightly less light than the T 12, but the smaller diameter of the T 8 traps less light within the fixture, allowing more light to be reflected. As a result, the same amount of usable light is produced for less energy. The T 8 lamps do need an electronic ballast (see *Ballast*) to operate.

Ballasts

Fluorescent lights need ballasts to operate - devices that control the electricity used by the unit for starting and circuit protection. Older magnetic ballasts, which were popular in the 60s and 70s, require about 16 watts (W) to operate two 40-W T12 lamps, for a total load of 96 W. With these ballasts, much of the energy is lost as heat. Such high-loss ballasts can no longer be sold in the United States. Instead energy-efficient magnetic ballasts are available that use high-grade materials and require approximately 8 W to operate two 40-W T12 lamps for a total load of 88 W. The new electromagnetic ballasts reduce ballast losses, fixture temperature, and system wattage. Because they operate at cooler temperatures, they last longer than standard electromagnetic ballasts.

Electronic high-frequency ballasts operate lamps using electronic switching power supply circuits. Electronic ballasts take incoming 60~Hz power and convert it to high-frequency AC (usually 20 to 40 kHz). Electronic ballasts are more efficient than magnetic ballasts in converting input power to the proper lamp power, The high operating frequencies reduce the darkening of lamp ends, which results in an overall lamp-ballast system efficiency increase of 15% to 20%.

Electronic ballasts have a number of other advantages over magnetic ballasts. Electronic ballasts are available that can operate three or four lamps per fixture, compared to two lamps for a magnetic ballast. Electronic ballasts are designed to operate lamps in either series or parallel mode. The advantage of the parallel mode of operation is that a single lamp failure will not affect the operation of the remaining lamps controlled by the same ballast. Other advantages of the electronic ballast include reduced weight, quieter operation, and reduced lamp flicker. Electronic ballasts are directly interchangeable with magnetic ballasts, and they are available to operate most full-size and compact fluorescent lamps.

Fixtures

Although lighting energy use is most often associated with lamps and ballasts, the light fixture also plays a role in delivering the light output where it is needed. Just as upgrading lamps and ballasts to more efficient models can reduce energy and costs, improved fixtures can also reduce energy costs. Where four lamps may be necessary in an older fixture to produce the needed light output, perhaps only two or three lamps would be necessary in a fixture with improved reflectivity.

The effectiveness and output of fluorescent lighting systems varies depending on the lamp, the ballast and the reflectivity of the fixture.

Lighting Controls

Lighting controls now offer a range of methods that are both cost effective and energy efficient. The simplest type is a standard snap switch. Other controls are photocells, timers, occupancy sensors, and dimmers.

- ***Wall switches, located in numerous convenient areas,*** make it easier for people in large, shared spaces to turn off lights in unused areas.

- ***Photo-cells turn lights on and off in response to natural light levels.*** Photo-cells switch outdoor lights on at dusk and off at dawn, for example. Advanced designs gradually raise and lower fluorescent light levels with changing daylight levels.

- ***Mechanical or electronic time clocks*** automatically turn on and off indoor or outdoor lights for security, safety, and tasks such as janitorial work. Crank timers, which are spring-driven and similar to old oven timers, limit lights to short durations where the need for light is brief.

- ***Occupancy sensors activate lights when a person is in the area*** and then turn off the lights after the person has left. They are popular for areas used infrequently, such as warehouses.

- ***Dimmers reduce the wattage and output of incandescent and fluorescent lamps.*** However, dimming makes incandescent lamps less efficient as they are dimmed. Dimming fluorescents requires special dimming ballasts and lamp holders, but does not reduce their efficiency.

Last but not least, ***make good use of sunlight***. If you are anticipating new construction, some careful thought to skylights, window placement, glass type and landscaping can go along way toward reducing or eliminating the need for electrical lamps during some of the daylight hours. You may find that a light efficiency project qualifies for a utility company's assistance program.

Fluorescent Lamp Disposal

All fluorescent lights contain small amounts of mercury, and some compact fluorescent lamps with magnetic ballasts contain small amounts of short-lived radioactive material. Because of these hazardous materials, you should not toss burned-out lamps and ballasts into the trash. Find out if there is a recycling program for them in your community, they are becoming more common. You may be able to dispose of them with other household hazardous wastes such as batteries, solvents, and paints at your community's designated drop-off point.

APPENDIX F

Preliminary Energy Assessments

Steve Bolles Woodard and Curran

Introduction

As part of an EPA initiative to explore alternative energy supply and cost saving technologies, a *preliminary energy review* was performed at the following five wastewater treatment facilities in Massachusetts, Maine and New Hampshire.

The Town of Montague, Massachusetts Wastewater Treatment Facility
The Veazie, Maine Sewer District Wastewater Treatment Facility
The Freeport, Maine Wastewater Treatment Facility
The Town of Berlin, New Hampshire Wastewater Treatment Facility
The Town of Groveton Wastewater Treatment Facility

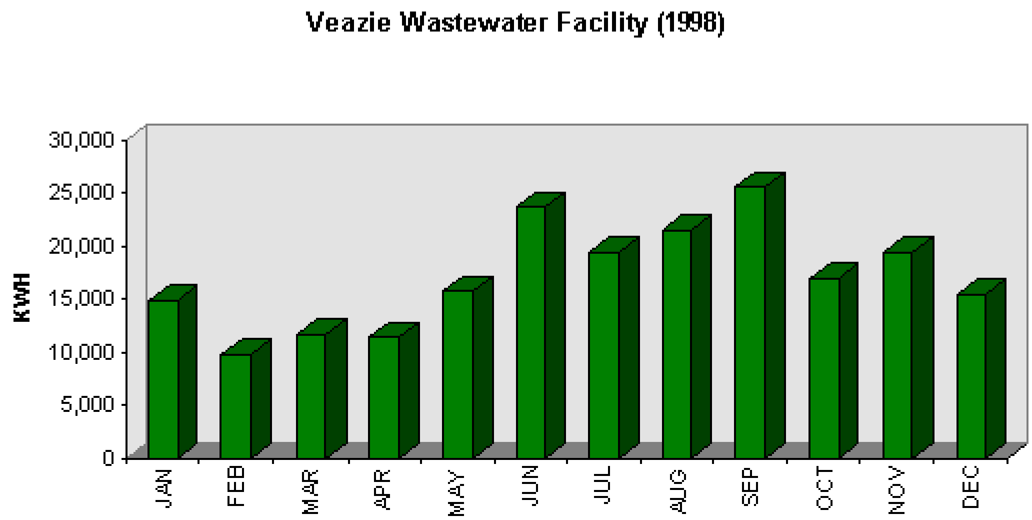
Although all of these facilities have made progress reducing energy costs through good operational practices, each facility was selected with the help of the New Hampshire, Maine and Massachusetts state environmental agencies based on the potential opportunity of exploring various energy saving technologies. The New England Interstate Environmental Training Center was chosen to help facilitate the project and evaluate how best to develop the findings into a training outreach program. Woodard & Curran assisted with the review of each of these facilities based on its experience performing energy evaluation work at over 50 facilities.

Veazie, Maine Wastewater Treatment Facility

The Veazie treatment facility consists of headworks, aerated facultative lagoons and chlorine disinfection. The primary energy use at the facility is the aeration system where floating mechanical aerators ranging from 2 hp to 7.5 hp are used. The facility has done well operating these units with timers as needed to match lagoon oxygen requirements.

Although energy conservation opportunities are limited at the facility, the construction of a new natural gas pipeline for a nearby power generation plant provides an opportunity to explore using natural gas as an alternative energy source for the treatment facility to reduce energy costs.

Energy use for the treatment facility is shown in the graph below:



Total energy use for 1998 was 205,682 kWh for a total cost of $21,080. This amounts to an average energy cost of $0.102 /kWh.

The lagoon system offers a fairly consistent electrical demand which combined with the availability of natural gas, makes the facility a good candidate for exploring the use of new micro turbine technology as a primary power source. Micro turbine gas fired generators offer an efficient alternative to reciprocating engines typically used at treatment facilities for emergency power. Some of the advantages of micro turbines include the following:

Designed for use as a primary continuous power source. Operating characteristics include low emissions, minimal maintenance and low noise.

Includes solid state power electronics to allow a parallel electric utility grid connection.

Generator is cooled by air flow thus eliminating the need for liquid cooling.

Produces oxygen-rich exhaust that can be used directly with heat exchangers to provide space heating for facilities.

Since the Veazie Sewer District is currently reviewing back-up power capabilities, the application of a micro turbine for low cost primary power, combined with the higher cost existing electric utility back-up power source, will increase system reliability.

A preliminary cost benefit analysis for applying the Capstone 28 kW Micro Turbine is shown below:

Month	**Avg kW**	**Capstone Turbine Fuel Consumption (Btu/hr)**	**Natural Gas in MCF (using a heating value of 905 Btu/cf)**	**Excess kWh Required From Electric Utility**
Jan	17.6	246,400	228	
Feb	15.0	210,000	150	
Mar	17.0	238,000	176	
Apr	17.5	245,000	175	
May	15.4	215,600	183	
Jun	29.0	410,000	358	792
Jul	30.0	410,000	293	1296
Aug	26.3	368,200	332	
Sep	29.0	410,000	391	864
Oct	31.0	410,000	250	1656
Nov	23.0	322,000	247	
Dec	18.9	264,600	238	
Total Energy Use			3021 MCF	4,608 kWh
*Total Electric Cost @$0.125/kWh and monthly fees				$800
**Total Fuel Cost @4.00/MCF			$12,084	
Total Energy Cost with Micro turbine			**$12,884**	

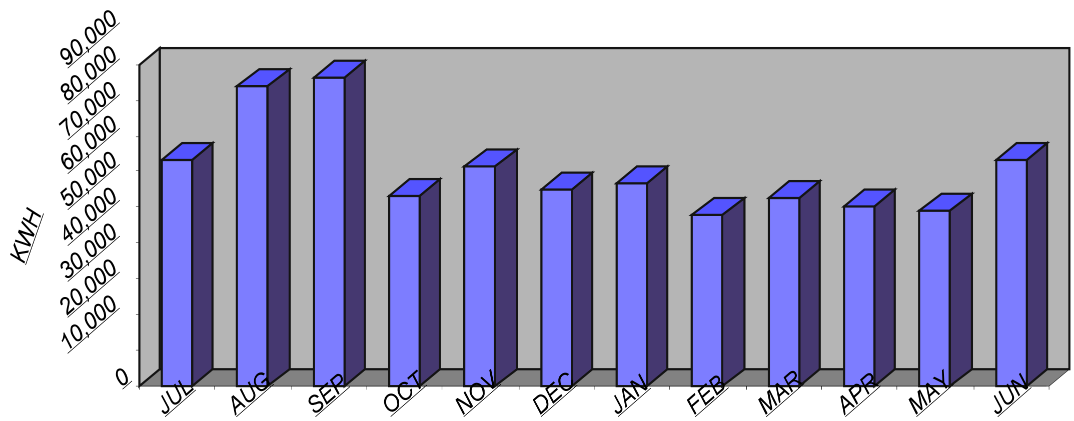
*The facility may be included under Bangor Hydro's general commercial rate due to a lower electrical demand
**Estimated cost for high pressure fuel service from pipeline

Energy cost savings is estimated to be $8,196 annually based on the above analysis. Maintenance escrow for major overhauls is estimated at $1,000 annually. Based on an estimated installation cost of $45,000 (not including gas line installation), a simple payback of 6.3 years could be realized.

These figures are for preliminary use only. The additional benefit of using waste heat for space heating, the avoided capital cost for installing an emergency generator (planned for next year) and the cost of installing the natural gas piping from the pipeline to the facility has not been included A more detailed review with a life cycle cost analysis is recommended.

Freeport, Maine Wastewater Treatment Facility

The Freeport Treatment Facility is an activated sludge facility with average flow of 300,000 gallons/day. The facility process includes the headworks, packaged primary treatment, aeration and sludge storage, and sludge dewatering with a belt filter press.



Total plant energy use for 1998/1999 was 723,880 kWh for a total cost of $66,908. This amounts to an average energy cost of $ 0.092/kWh.

The facility was selected based on the following opportunities for energy conservation.

Four 75 hp Hoffman multistage blowers are currently available for providing wastewater aeration, compressed air for the air lift pumps, and aeration for sludge storage. One blower is used at a time on a continuous basis. Although the facility has identified which blowers are most efficient and operates these blowers more often, the use of these blowers for multiple purposes makes it difficult to optimize the system.

The Porter Landing Pump Station is an older pump station that pumps the majority of flow to the treatment plant (242,000 gallons per day). The station is equipped with two 50 hp Smith and Loveless pumps.

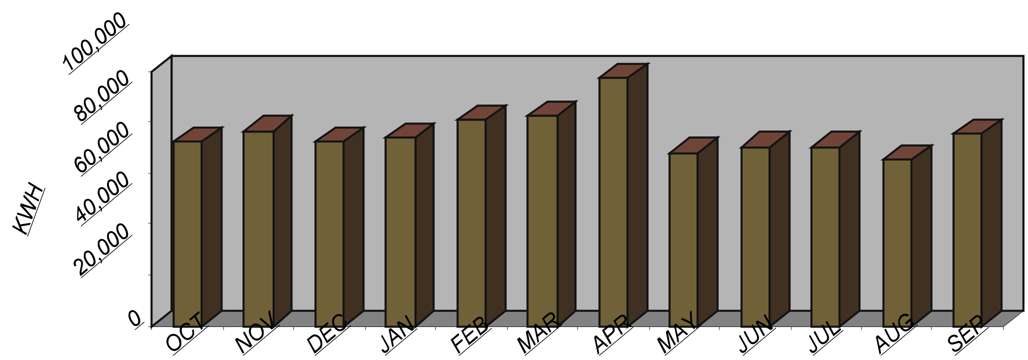
To evaluate how best to improve the efficiency of the blower system, air requirements for each process needs to be determined. The air lift pump transfers 60 gpm waste activated sludge from the secondary settling tanks to the sludge holding tanks approximately one hour/day. The estimated air requirement for this is 1200 cfm. The power per cfm is estimated at 0.05hp/cfm. Based on a wire to air efficiency of 0.70, this corresponds to an energy use of _____. Although the air lift pumps have been a reliable, low maintenance system for transferring sludge, it is also an inefficient method compared to using small horsepower, submersible transfer pumps for this process.

Using aeration for freshening the sludge holding tank may still be an efficient way to accomplish aeration if it is done on a limited basis, installing a small blower dedicated for sludge should only be considered if this must be done on a regular basis.

After a determination of what air flows are needed for the aeration process, we would expect that the blower size could be reduced significantly. This could possible be done by de-rating the existing multistage blowers to produce lower air flows or investigating smaller blowers with an automatic dissolved oxygen control system. In either case, this project should be considered to reduce facility energy use.

The Porter Landing Pump Station pumps the majority of flow to the facility. Based on pump curve characteristics, and the number of hours the pumps currently operate, the application of variable speed drives could reduce pumping costs. To evaluate the system the Pump Systems Assessment Tool Software (PSAT) developed by the Department of Energy Motor Challenge Program can be used. When used in conjunction with the pump system curve, the PSAT program can help evaluate if a reduction in pipe friction would provide enough cost savings to justify variable speed drives or a smaller pump.

City of Berlin, New Hampshire Pollution Control Facility



Total energy use for the 12 months shown above was 905,520 kWh for a total cost of $101,579. This amounts to an average energy cost of $0.112 /kWh.

A simple calculation to determine the feasibility of a hydrogeneration system is as follows:

Head (vertical drop in feet) * Flow available (gpm) * .18 (average efficiency).

35 ft. * 555 gpm (average flow of 800,000 mgd) * .18 = 3496 watts (3.5 kW)

Based on the above estimate of 3.5 kW, a small turbine system located at the end of the facility outfall could generate approximately 30,000 kWh per year, saving $3000 annually (based on $0.10/kWh). With an estimated project cost of $15,000, a simple payback of 5 years could be realized.

Energy conservation was also evaluated for the treatment facility. The treatment process begins with the pumping of wastewater in the collection system by five pump stations. This flow is directed to the Watson Street Pump Station which serves as the main pump station where flow is pumped to the treatment plant. At the plant the flow is processed through the headworks structure, aerated grit removal system, primary treatment, aeration basins, final clarifiers and disinfected at the chlorine contact tanks. Sludge is thickened in gravity thickeners and dewatered with centrifuges.

The Watson Street Pump Station is equipped with three 125 hp variable speed pumps capable of 4000 gpm at 76 ft. TDH. Eddy current magnetic clutch variable speed drives have been replaced with new Eaton pulse width modulation AC variable speed drives several years ago.

A review of the pump station log sheets indicates that the lead pump operates almost constantly (24 hours/day). At a low flow of 555 gpm (800,000 mgd) during the evening hours, the manufacturers pump curves indicates that the pump efficiency *is approximately 55%.* Although this can be adjusted fairly easily by programming a higher minimum operating setpoint for the variable speed drives, a more comprehensive review of the pump system can be developed using the Pump Systems Assessment Tool Software (PSAT) developed by the Department of Energy Motor Challenge Program since even the full load efficiency of the pumps was only 75%.

To provide a simplified review of how a 20% reduction in efficiency for this pump system translates into energy dollars, the following comparison can be made:

Pump System at Average Wire-to-Water Efficiency of 55%

$$\text{kWh} = \frac{\text{1388 gpm (2.0 mgd average flow)} * \text{43 ft. TDH} * .746\ \text{kW/hp} * \text{8760 hours/year}}{3960 * .55}$$

kWh = 179,078 kWh

Pump System at Average Wire-to-Water Efficiency of 75%

$$\text{kWh} = \frac{\text{1388 gpm (2.0 mgd average flow)} * \text{43 ft. TDH} * .746\ \text{kW/hp} * \text{8760 hours/year}}{3960 * .75}$$

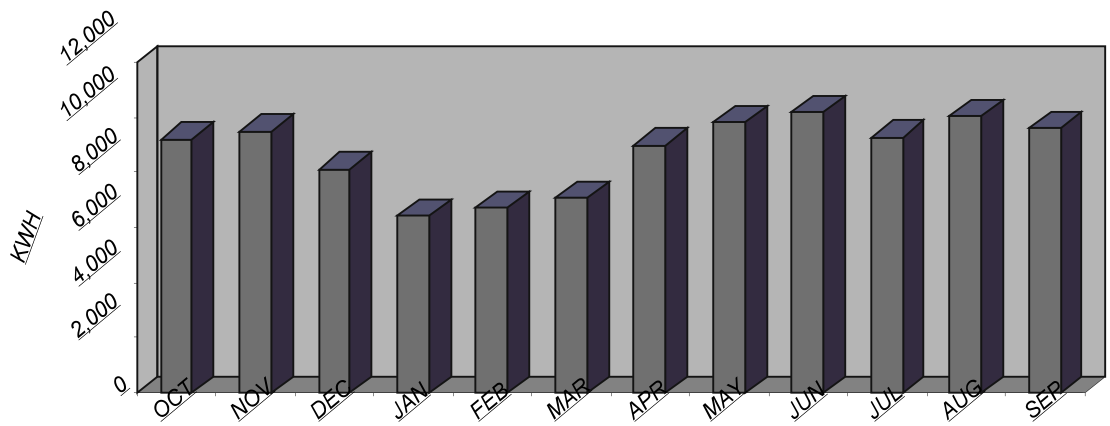
kWh = 131,324 kWh

Annual Savings: 179,078 - 131,324 = 47,754 kWh
47,754 * $0.10 = $4,775

The aeration system consist of fine bubble membrane diffusers, and 75 hp Hoffman multistage centrifugal blowers. With an average dissolved oxygen level of 1.0 to 1.5 mg/l maintained in the aeration tanks, it does not appear that a more automated control system will provide much savings. However, the facility is currently considering replacing the existing blowers with new positive displacement (PD) blowers equipped with variable speed drives.

Groveton, New Hampshire Wastewater Treatment Facility

The Groveton Facility consists of 2 facultative lagoons. Four 5 hp mechanical surface aerators are used with timers to maintain suitable dissolved oxygen levels. Energy use for 1998/99 is shown below



Total energy use for the 12 months noted above was 105,120 kWh for a total cost of $10,492. This amounts to an average energy cost of $0.10 /kWh.

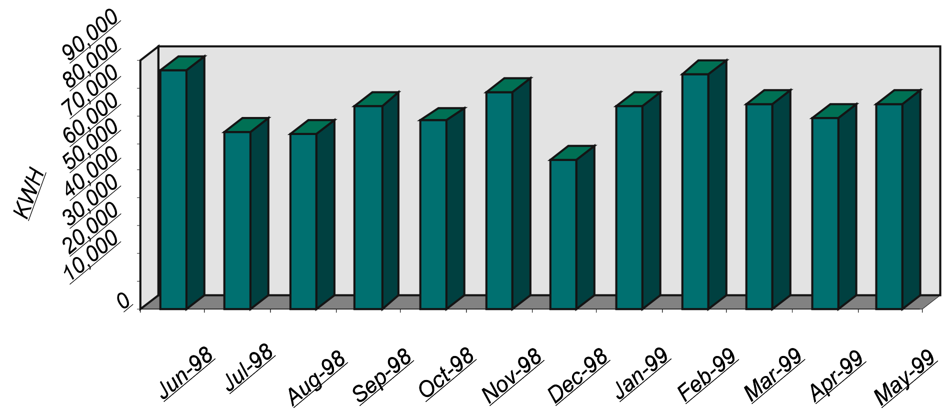
The Groveton facility was selected for alternative energy potential based on a consistent wind created from its valley location adjacent to several nearby mountains. The operator of the facility maintains that the wind is in the 10 to 14 mph range the majority of the time.

The facility appeared to be well suited for wind powered aerators. LAS International was contacted to evaluate the use of their Mark 3 wind powered aerators. The units can operate at a minimum wind speed of 4 mph, but can also withstand winds in excess of 80 mph. The aerators can also be equipped with a ¾ hp electrical motor that can be activated by low dissolved oxygen levels or wind speed.

LAS claims that their aerators increase DO levels without disturbing the critical sludge-digestion zone. The unit processors also distribute the organic loading throughout the cells, allowing the total cell volume to be fully productive. The company indicates that the units typically have a simple payback of 2 to 3 years.

Montague, MA WWTF

The Montague facility is a conventional activated sludge facility designed for an average flow of 1.865 million gallons per day (MGD). Average flow is currently 1.03 MGD. Energy use for 1998/1999 is shown below.



Total energy use for 1998 was 862,560 kWh for a total cost of $69,338. This amounts to an average energy cost of $0.080/kWh.

In the last few years, the facility has been aggressive pursuing energy conservation projects in the facility. These projects include:

Installing variable speed drives and automatic blower controls on their aeration system. This project is expected to go on line by the end of 1999 and is projected to reduce annual energy costs by approximately $30,000 (per energy evaluation performed in 1998)

Replacing one of the existing 30 hp plant water pumps with a 15 hp unit. Based on a previous evaluation, this improvement is expected to save $5,688.

In addition to the energy projects currently being installed, the facility has also had experience with a small hydro generator that was installed 15 years ago. The system was not ideal for a hydro generator and had flooding problems when the river elevation increased during certain times of the year, and would also get clogged with leaves occasionally. The generator has not been used in five years and must be reviewed in more detail to determine if a hydro generator could be applied more effectively.

Although energy use is expected to be reduced significantly with the aeration and plant water system projects, upon a review of the facilities operation and maintenance expenses, *sludge disposal costs were over four times higher than annual energy costs.* Woodard & Curran considers this facility to be an excellent candidate for an *electrotechnology*. Electrotechnologies involve the application of equipment that may increase energy costs, but provide enough savings in other operational expenses to justify the recommended improvement.

Based on annual sludge disposal costs of $328,000, a sludge drying system may be a cost effective project. Woodard & Curran has recently installed a dryer in its Gloucester, MA WWTF and is expecting to reduce disposal costs by over 60% (net saving take into account energy and maintenance expenses). This needs to be reviewed in more detail to determine the best approach for the Montague facility.